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PLUM ROOTSTOCK STUDIES: THEIR EFFECT ON THE VIGOUR AND CROPPING OF THE SCION VARIETY

By **R. G. HATTON**
East Malling Research Station

THE first progress report on this subject appeared in 1928 (1). The problem was then set out so fully that it need not again be discussed in detail.

The preliminary work of classification and description (2) showed that in Europe a considerable range of varieties which appeared to represent at least three or four species (P. domestica, P. insititia, P. cerasifera and P. munsoniana) were in use, almost indiscriminately, as rootstocks. Whilst some of these were of clonal origin and vegetatively raised (such as the Brussels and various Mussels), the majority of those in wide circulation on the Continent of Europe (i.e. the Myrobolan, St. Julien and Black Damas) were of seedling origin. To complicate matters further, different countries and even small localities had introduced as rootstocks varieties plentiful in their district as a prolific source of seed (such as the Kroosjes of Holland) or suckers (such as the Yellow Egg or Pershore of Worcestershire, England).

The first task in building up this investigation upon a sound basis was the establishment of clonal races. This involved a series of propagation experiments (2) which eventually yielded the vegetative races of rootstocks upon which the main and later series of field trials were based. Whilst some plum stock varieties (Brussels, Common Plum) responded readily to etiolation methods, others (Mussel and Brompton) came as readily, if not more so, from root cuttings, and a few propagated easily from wood cuttings (Marianna and Myrobolan B.), others, such as Yellow Egg, have as yet, unfortunately, not become sufficiently amenable to any form of a-sexual propagation to bring them within the range of general commercial adoption. Though it is not the place here to enter further into this aspect of the investigation, mention will be made of a small comparative trial of these different methods of reproduction in so far as it might affect the scion variety.

Great difficulty was experienced in limiting the number of selections which had to be made from the seedling families of Myrobolan, St. Julien and Black Damas—so infinite appeared to be the variations amongst seedling plants sold under these names. Selection went along several lines—botanical characteristics of leaf size and shape; general habit of growth and, finally, appearance of fruit, were first employed, and type plants which corresponded closely to varieties which seemed to recur in the many collections of seedlings examined were picked out as representative of the most extreme differences. The vegetative characteristics of these different " type " plants have already been fully described (2)—the broad and narrow, green and yellow leaved Myrobolans, and the dark green curled and flat glaucous leaved St. Juliens—thorny and spineless —the fruits of which have been found to vary from a typical damson to a greengage. These " type " plants were then subjected to nursery tests as to ease of propagation and readiness to take the bud, for it was only if they possessed these characteristics that they could be included in the trials at all. It was of course impossible to predict whether their influence as rootstocks would be good, bad or indifferent, and even after this lapse of years there is no intention of claiming that the representative Myrobolans and St. Juliens picked out of many thousands of seedlings at East Malling are by any means the best possible among such wide variety. Fortunately the East Malling Myrobolan B, St. Julien A and B and Black Damas C, all appear to possess characteristics which suggest that they are at least not unworthy clonal representatives of these mixed races.

The planning of the field experiments was no easy matter in view of the equally wide range of P. domestica varieties grown in England. As later experience has shown, it might have been wiser to have confined the investigations for the first few years at least to a series of nursery trials which might have revealed a number of those " incompatibilities " between plum rootstock and scion which have largely been discovered in the course of routine. On the other hand, the experience gained in technique in the planting and conduct of a succession of field trials embracing a wide and representative range of scion varieties has proved ample compensation.

Besides including cultivated varieties of P. insititia, such as Cluster and Prune Damson and Black Bullace ; of P. cerasifera, the Red Cherry Plum ; a range of P. domestica, designed to cover the different types of " round " and " long ", " blue ", " red " and " yellow " plum, " gage " and " prune " varieties were selected, in the hope that some general principle might evolve.

The plan of making comparatively small units of each combination of stock and scion and of reduplicating the experiment by successional plantings has been described elsewhere (1). The first series at East Malling was planted upon " commercial " stocks, bought in, and identified and rogued before being worked. All the later series were worked upon East Malling clonal material. In the early years small duplicate plots were planted on various soils other than East Malling. These were kept under observation sufficiently long to enable the writer to draw the conclusion that the general results were confirmatory of the central experiments at the Research Station, but the units of trees were too small, especially where the incidence of disease supervened, to justify the continuation of detailed measurements.

The field trials at East Malling have been considerably disturbed by two diseases, first by Silver Leaf (*Stereum purpurem*) and later by Bacterial Dieback (*Pseudomonas mors-prunorum*), as well as by manifestations of " delayed incompatibility " upon such rootstocks as Brussels and Common Plum with certain scion varieties. This mortality has been sufficiently serious to justify some careful analysis, and whilst it at once becomes clear that varietal susceptibility has been the main feature, there is evidence that in some cases rootstock influence is not absent. Fortunately in the later series of trials a sufficiency of healthy trees has survived to render statistical treatment of the weights and measurements still possible. Methods of pruning and spraying have been adapted to render the control of the diseases more successful, and many of the unpromising combinations of stock and scion recognized and eliminated.

It has not been possible to take as complete records of tree performance in the case of plums as in that of apples. The nature and quality of the growth made it impossible after the very early years to continue any form of wood measurement. Reliance has had to be placed upon annual girth measurements, together with height and spread of the head and branches. The first series of trees has already been grubbed and weighed and it is encouraging to see how far these total tree weight figures have fallen into line with the girth measurements. These were reflected in the total measurements of wood growth taken in the early years and already published (1). Since the fruit has to be " picked over " for colour and ripeness a number of times and marketed quickly, it is not an easy matter to obtain detailed records beyond those of total weight per tree, though from time to time the number of fruits in a given weight of fruit has been taken and the amount of fruit ripening over a given period of harvesting has been recorded. The various records are discussed in greater detail when the data are brought under review.

THE INFLUENCE OF METHODS OF VEGETATIVE PROPAGATION UPON THE ULTIMATE SCION.

Since it appeared likely that different methods of vegetative propagation—such as layering, root cuttings and wood cuttings—might eventually need to be recommended as the most economical method of raising individual varieties of rootstock, a small trial was designed to ascertain whether the same rootstock, produced in various ways, showed any marked difference in its ultimate effect upon the scion.

The rootstock Brompton was chosen as being fairly amenable to all these methods, although the roots produced from wood cuttings were initially less vigorous than those from layers or root cuttings. When lifting at the end of the first season the roots of the layer appear to arise mostly from the base of the stock, whereas on the root cutting they may come from various situations on the root-piece. When some of these stocks, raised by the three methods, were lifted at a later stage, it appeared that these differences had largely "evened up" in character and that the stocks were typically Brompton.

A series of these stocks were budded with Victoria and Table I gives the relative heights of the one year old trees, and the weight of the two year olds at the time of lifting and transplanting.

TABLE I.

Mean Height of One Year Old Trees and Weight of Two Year Old Victorias on Brompton stocks propagated by different methods.

	Layers.	Wood Cuttings.	Root Cuttings.
Mean Height of one year olds (cms.)	131	124	116
Mean Weight of two year olds (kilos.)	1·19	1·06	1·02

At the end of the first season the trees on layers were significantly taller than those on root cuttings—those on wood cuttings being intermediate. When they were lifted for transplanting a year later, although the mean weight of the trees on layered stocks was somewhat heavier, the difference was not large enough to be significant.

For the comparatively small differences which it was hoped to detect, the unit of trees available for the experiment was all too few and unfortunately this series of trees was reduced nearly fifty per cent. by Bacterial Dieback. However, since the remaining healthy trees are now fourteen years old, the data collected is here presented, since it at least suggests that the vegetative method of raising the stock is unimportant except in so far as it affects the tree's initial start so that it remains a larger or smaller individual in its characteristic group just as it came from the nursery. Table II gives the available data.

TABLE II.

Victoria Plums on Brompton rootstock raised by different vegetative methods. (Planted in 1922—two years—now fourteen years old.)

	No. of Trees.		Wood Growth 1921-25. cms.	Area Cross Section of stem—1934. sq. cms.	Head Height—Spread. 1933. metres.		Total Fruit to 1934. kilos.
	1922.	1934.					
Layers	10	7	4,098*	162·3	3·2	4·8	155·3
Root cuttings ..	10	5	3,310*	144·1	3·3	4·7	143·9
Wood cuttings ..	9	5	3,724	138·8	3·3	4·8	167·5

* The trees on layers made significantly more wood growth than those on root cuttings at the end of 1925, those on wood cuttings being intermediate.

As the Table shows, at the end of 1925 the trees upon root cuttings were still significantly smaller than those upon layers as measured by their wood growth. However, nine years later there was a significant difference between the areas of cross section of stem of the trees on stocks raised from wood cuttings and those budded on layers, those trees on stocks from root cuttings being now intermediate. In other respects the differences are not significant. It is hoped sooner or later to excavate the root systems of these trees in order to obtain details of their morphology now that they have reached maturity.

It is intended to investigate this subject more thoroughly when time permits, especially in view of the evidence brought forward by Woodhead (4) of the different performance of apple trees on layers and root cuttings from Northern Spy.

CLONAL SELECTIONS FROM SEEDLING MYROBOLAN, ST. JULIEN AND BLACK DAMAS ROOTSTOCKS.

As has been mentioned earlier in this and in other reports upon this subject, selections, which appeared to be typical of the range of variation recorded in some thousands of commercial seedling stocks, were propagated vegetatively at East Malling. It is now possible to compare the behaviour of certain varieties budded upon these clonal races and to show just how far this variability manifests itself in the scion variety.

It is not proposed here to do more than draw attention to the nursery aspect of the problem, by referring to the data (already published) dealing with the different degrees of compatibility possessed by different clonal selections of the same variety, when budded with a single scion (5). Fortunately for the fruit grower, this phenomenon automatically eliminates many an unsatisfactory tree before it reaches the plantation, though he probably has to pay his share of the disappointment with the poor " take " of buds and high mortality in the nursery due to the inter-mixture of incompatible seedlings.

There are three series of trees available ranging from thirteen to nine years old. The oldest series consisted of thirty-eight trees of Victoria budded upon the clonal Myrobolan selections, Malling A, B, C and D, which are fully described elsewhere (2).

Table III gives the history of these trees to the end of 1934.

Whilst there is a suggestion throughout that the trees on Myrobolan B have been slightly more vigorous and better cropping, the figures, with the exception of the small crop on Myrobolan A, compared with that on B, are just not significant at thirteen years. However, before concluding that these Myrobolan clones are so alike in their influence upon the scion that it might be equally safe to use seedlings, it will be well to study the second series of trees, eleven years old, budded with Czar, which is a variety known to show stock preferences

TABLE III.

Comparative behaviour of Victoria on four clonal Myrobolans.
(*Planted* 1922—*thirteen years.*)

	No. of Trees.		Wood Growth in cms. 1922-25.	Area Cross Section Trunk in sq. cms. 1934.	Height and Spread in metres. 1933.		Total Fruit in kilos. to 1934.
	1922.	1934.					
Myrobolan							
B ..	10	5	2,756	174·1	3·2	4·9	179·7
C ..	8	8	2,261	168·4	3·0	4·8	147·4
D ..	10	5	2,148	168·1	3·1	4·9	141·2
A ..	10	7	2,346	168·1	3·1	4·9	133·9

readily. To the same four Myrobolan clones there was added a fifth Myrobolan originally obtained from the Continent as Myrobolan Blanc and known after clonal reselection at East Malling as selection E. Table IV shows the performance of the trees.

In the case of Czar the trees on C, D and B are significantly more vigorous than those on A and E, and again the crops from the trees on A, though very variable, are this time significantly at the bottom of the list. It therefore seems reasonable to suppose that real, if small, differences in the influence of Myrobolan rootstocks are just becoming apparent, though it has always been realized that the vast majority of Myrobolan seedlings gave vigorous trees, at first slow to crop. Were it not for the differences in the nursery behaviour of the buds of certain varieties upon these clonal races in certain seasons, the vegetative raising of Myrobolans might not be considered a necessary economic measure. Fortunately one of the selections, Myrobolan B, propagates very readily from layers and cuttings, it takes the buds of all varieties so far tested at the Station well, it

TABLE IV.

Comparative behaviour of Czar on five clonal Myrobolans.
(*Planted* 1926—*two years—eleven years old.*)

	No. of Trees.		Area Cross Section of Trunk in sq. cms.		Height and Spread in metres.		Total Fruit in kilos. to 1934.
	1926.	1934.	1928.	1934.			
Myrobolan							
C ..	12	12	9·6	100·0	3·1	4·1	89·9
D ..	12	10	10·2	98·0	3·3	4·2	86·7*
B ..	12	9	8·8	90·6	3·1	4·2	91·7
A ..	12	6	9·5	75·7	3·0	3·4	61·3
E ..	4	4	9·3	67·1	2·4	3·4	69·0*

* These differences are not significant.

is as vigorous as the other selections, and in both trials heads the list in cropping. The adoption of such a clonal stock also obviates the necessity of relying on imported seed.

However, as might be expected, the situation is far more striking in the case of the St. Julien and Black Damas clonal selections. As has been reported elsewhere, these are extremely variable in their foliage and growth characters (2, 6) and when they came into bearing they were found to be equally diverse (6). Some propagate very much more readily than others, and again the manifestations of incompatibility in the nursery suggest that these seedling races of stocks must be regarded with grave suspicion.

A plantation of eighty two year old Czar plums budded upon six of these St. Julien and Black Damas clones with trees on the vigorous Myrobolan B and moderately vigorous Common Mussel was set out in 1928. Table V records the performance of the trees to date.

TABLE V.

Comparison of Czar plums on clonal St. Juliens, Black Damas, Myrobolan B and Common Mussel. (*Planted February* 1928 *as two year olds—nine years old.*)

	No. of Trees.		Area Cross Section of Stem in sq. cms.		Height and Spread of Head in metres.		Total Fruit in kilos. to 1934.
	1928.	1934.	1927.	1934.	1934.		
Damas A ..	10	9	5·2	77·1	3·1	3·5	32·0
Myrobolan B ..	10	9	4·8	72·9	3·2	3·4	29·9
St. Julien B ..	10	10	4·2	61·6	2·8	2·9	29·8
Damas C ..	10	10	4·0	49·9	2·6	3·0	23·9
St. Julien A ..	10	10	3·6	42·1	2·4	2·9	19·8*
C. Mussel ..	10	8	3·5	40·8	2·4	2·6	14·6*
St. Julien D ..	10	9	3·9	34·9	2·2	2·1	10·9
St. Julien C ..	10	9	3·8	33·5	2·0	2·2	15·6*

* These differences are not significant.

First of all it is extremely interesting to find in Damas A—reputed insititia and therefore dwarfing type—a rootstock as vigorous as the most vigorous Myrobolan; whilst Damas C is bracketed in vigour with the intermediate Common Mussel, and has cropped slightly better. Whilst none of the trees on selected St. Juliens appear in the most vigorous group with Myrobolan B, St. Julien B stands in an intermediate group by itself and has cropped as well as any. The area of cross section of stem of these trees is practically double that of the trees on St. Julien C (61·6:33·5) which stands at the bottom of the list, whilst they have given nearly three times the crop of the trees on St. Julien D. Here indeed is a striking range of vigour and performance amongst these typical clonal races of St. Julien and Damas of which seedling races were at one time very popular.

It is hoped from amongst these and similar selections to find one or more plum rootstocks which give a really prolific dwarf tree, which might replace the Common Plum because it is at best only a semi-dwarf and proves incompatible to so many important varieties.

It is early days yet to make any final selection for commercial introduction, though a few experimental consignments of Damas C and St. Julien B have been circulated for the attention and criticism of interested nurserymen.

Whilst the results to date suggest that certain varieties or species of plum such as the P. cerasifera may be grown in many respects comparatively uniform from seed, they also show that other varieties, such as the St. Juliens and Black Damas, which have been grouped by Hedrick (4) as P. insititia, cannot be relied upon to produce anything approaching uniform trees, though they may prove a fertile race from which to seek rootstocks of diverse potentialities.

PLUM VARIETIES ON THEIR OWN ROOTS.

Ever since 1920 attempts have been made at East Malling to establish a number of plum varieties upon their own roots to compare their behaviour with similar trees budded or grafted upon the stems of other rootstocks. Three series, comprising over three hundred trees, have been planted and are now from nine to thirteen years old. As experience accumulated, so the technique of propagation and plot lay-out improved, and the last experimental planting of two year old trees in January 1928 is by far the most complete and satisfactory. Although the diseases which have so continually disturbed the plum rootstock investigations at the Station are as yet by no means completely under control, one hundred and ninety-five trees of four varieties upon four different root systems have survived and are continuing to grow healthily, so that the nine years' records upon this material deserve detailed examination. The first and second series of trees, planted in 1921 and 1924 respectively, afford interesting supplementary evidence, interpreted in the light of the information gained from the more exhaustive trial (series 3).

In the first progress report reference was made to the primary reasons for using budding and grafting methods upon selected plum rootstocks. It was suggested that, whilst quite a number of local sorts of varying character were grown upon their own roots and propagated subsequently from suckers arising therefrom, probably the majority of better known varieties would prove difficult to grow and multiply by such methods. Whilst this hypothesis has been largely borne out by the nursery trials carried out by the Propagation Section, there have been enough exceptions to make possible the planting of quite a representative plantation consisting of trees of the following varieties: Victoria, Yellow

Egg (Pershore), Cambridge Gage and Cluster Damson, growing upon their own roots, upon the vigorous Myrobolan B (E.M. selection of P. cerasifera), upon the usually dwarfing Common Plum (a vegetatively raised P. insititia type) and the intermediate Common Mussel rootstock (insititia type) which encourages early productivity. Forty trees of a local Eastern County variety—Bastard Victoria—reputed for its hardiness, were also included in the main series, but they proved so susceptible to Bacterial Dieback (*Pseudomonas mors-prunorum*) that they were all removed in 1931 and detailed observations had been discontinued upon them for some time previously.

At the time they were removed, nine trees were already dead, or so severely affected that they would not have been likely to recover, while another nine were suffering from the disease in a less advanced stage. Thus nearly fifty per cent. of the trees were useless from an experimental point of view.

Although the vast majority of plum varieties—whether selected for their fruit or for their value as rootstocks—have never been quite so easy to raise vegetatively as apples, the following Table, prepared by Mr. A. W. Witt, compares the rooting capabilities of these four varieties with those of some of the most easily raised and intractable rootstocks.

TABLE VI.

Comparison of rooting capabilities of certain scion varieties, with varieties commonly used as rootstocks.

	Percentage Shoots rooted from Layers.				
	1921.	1922.	1923.	1924.	1926.
Myrobolan B	95	95	95	91	—
Brompton	35	20	50	40	70
Common Mussel	70	70	75	40	75
Victoria	—	—	40	40	72
Pershore Egg	—	15	40	20	70
Cambridge Gage	65	70	70	70	—
Cluster Damson	40	10	30	30	—
Bastard Victoria	90	95	90	90	—

This comparison should be borne in mind when considering the behaviour of the nine year old trees. The comparative ease with which the variety Victoria has been found to respond to layering methods is as interesting as it was unsuspected.

The Propagation Section has, for various experimental requirements, attempted in addition to obtain the following varieties upon their own roots. These, with the above, may be grouped as follows:

Ready Rooting.	*Moderate.*	*Indifferent.*
Denniston's Superb	Victoria	President
Bastard Victoria	Pershore Egg	Utility
Cambridge Gage	Warwickshire Drooper	Kea
	Purple Egg	Czar
	Blaisdon Red	Rivers' Early Prolific
	Bastard Orleans	Evesham Wonder
		Westmorland Damson
		Cluster Damson
		Harnetts Bush.

It should also be borne in mind that the three rootstocks chosen for their different influence upon the tree's vigour and cropping happened to be amongst those which root most readily, so that from the outset in the nursery the trees budded upon these already well developed young root systems had a rather better start than the less ready rooting layers of Yellow Egg, Cambridge Gage and Cluster Damson. In order to secure as comparable trees as possible for transplanting, a sufficiency of clonal material of the four varieties and the three rootstocks was layered ; and the best rooted (by etiolation methods) from amongst the one year shoots arising therefrom were severed and transplanted in the dormant season at normal nursery distances. They were all left to grow until the budding season, when the buds of the four varieties were inserted into the three rootstocks. When the time arrived for "snagging" or beheading the stocks just above the buds, the following spring, the unbudded layers of Victoria, Yellow Egg, Cambridge Gage and Cluster Damson were cut back at a similar height. This treatment induced them to send out a clean maiden growth from a dormant bud similar to that from the budded stocks—all surplus growths being kept rubbed out in both cases. At the end of the first season, after measurements of maiden growth had been taken, all the trees were headed back uniformly at 137 cms. and allowed to form heads in the nursery for a second year before transplanting. The following records give some idea of the uniformity of the material when it was set out in its permanent position.

Table VII shows the number of two year old trees which were available for planting out in January 1928, together with the measurements which were made at the time. These include the two years' measurements of wood growth, and the average weight and cross section of stem when they were lifted. In three cases out of the four the trees on their own roots were then quite up to the standard of those budded upon Myrobolan B and Common Mussel, and rather more vigorous than those on Common Plum. In only one case, Cluster Damson, were they appreciably smaller than the budded trees. In this instance there were no trees upon Common Plum as this particular combination is

TABLE VII.

Average weight, cross section of stem and two years' wood growth of two year old trees of Victoria, Cambridge Gage, Pershore Egg and Cluster Damson available for planting out.

	No. of Trees.	Weight. gms.	Cross Section of Stem. sq. cms.	Wood Growth. cms.
VICTORIA.				
On Own Roots ..	15	936	3·7	466
Myrobolan B ..	17	907	3·5	308
Common Mussel ..	17	595	2·3	144
Common Plum ..	21	936	3·5	300
CAMBRIDGE GAGE.				
On Own Roots ..	20	867	4·0	329
Myrobolan B ..	16	1,049	5·4	477
Common Mussel ..	17	737	3·6	307
Common Plum ..	15	822	3·9	415
PERSHORE EGG.				
On Own Roots ..	25	1,052	4·2	443
Myrobolan B ..	17	1,140	5·0	501
Common Mussel ..	16	953	4·2	378
Common Plum ..	16	729	3·2	318
CLUSTER DAMSON.				
On Own Roots ..	19	765	2·9	8
Myrobolan B ..	15	896	3·2	Not Measured.
Common Mussel ..	16	859	3·2	8

incompatible. The treatment of the trees from the time of transplanting up to the end of 1934 can be briefly summarized as follows:

All the trees were cut back hard when they were planted in January 1928 and leader tipped for three years subsequently—the pruning being done in April.

The trees were interplanted with standard cherries planted at the same time, being 15 ft. apart in the cherry rows and 30 ft. between the rows. This allowed for under cropping with strawberries from the autumn of 1928 until the end of 1933, when the strawberries were replaced by black currants.

The manurial treatment has been uniform throughout and where the under crops were planted in different seasons the plantings were so arranged as not to interfere with the inter-comparison of the plum stock trials.

The annual measurement of all new wood growth and even an estimate of the blossom buds soon become a very difficult matter in a plum tree ; so that the annual increment in cross section of stem, supplemented by the height and spread of the branches from the main fork must be relied upon as the main expressions of comparative vigour, until such time as the trees can be dug up and weighed. Similarly total weight of fruit harvested has to serve as the measure of the tree's productivity. The following Table summarizes these records :

TABLE VIII.

Comparison of plum varieties on own roots and budded on certain stocks.
(*Planted as two year olds, January* 1928—*nine years.*)

	No. of Trees.		Area Cross Section of Stem in sq. cms.		Height and Spread of Head in metres.		Fruit in kilos. to 1934.
	1927.	1934.	1927.	1934.	1934.		
VICTORIA.							
On Own Roots ..	10	8	4·0	90·9	2·3	3·9	35·9
Myrobolan B ..	10	9	3·6	78·1	2·6	3·8	15·9*
Common Mussel ..	8	7	2·5	50·5	2·0	3·4	22·2
Common Plum ..	12	12	3·5	49·9	2·3	3·6	16·8*
YELLOW EGG.							
On Myrobolan B ..	10	9	5·1	109·7	3·2	4·0	44·1
Own Roots	10	9	4·4	86·3	2·8	3·6	43·6
Common Mussel ..	10	10	3·8	73·5	2·7	3·4	27·5
Common Plum ..	10	10	3·5	46·1	2·1	3·0	23·9
CAMBRIDGE GAGE.							
On Myrobolan B ..	10	10	5·2	195·7	3·1	4·8	16·8
Own Roots	10	10	4·2	146·7	2·9	4·1	11·4
Common Mussel ..	10	10	3·8	124·3	2·8	4·2	11·7
Common Plum ..	10	10	3·9	99·9	2·4	3·9	8·2
CLUSTER DAMSON.							
On Myrobolan B ..	14	14	3·3	90·9	3·0	3·9	53·6
Common Mussel ..	7	7	3·4	62·5	2·4	3·6	43·1
Own Roots	18	18	2·9	58·1	2·4	3·7	35·9
Common Plum ..	(Incompatible.)						

The brackets show where differences are not significant.

* These differences are not significant.

It is interesting to note that of the six casualties to trees from Bacterial Dieback, three have been "own rooted" trees, two on Myrobolan B, one on Common Mussel and none on Common Plum. This does not support the theory at one time advanced that trees growing upon their own roots were always the most hardy.

In three out of the four cases—Yellow Egg, Cambridge Gage and Cluster Damson—the trees on Myrobolan B are significantly more vigorous than the same varieties growing on their own roots, up to the end of the ninth year. In the case of Victoria the difference in favour of the trees on their own roots is very suggestive, though at present the figures are just not significant. In three out of the four comparisons the trees on the intermediate stock, Common Mussel, do not differ significantly in vigour from those on their own roots. Victoria again proves the exception. In all these comparisons the trees on Common Plum are significantly more dwarfed than those on their own roots. Thus at the end of nine years it is possible to claim that plum varieties have been made both more vigorous and more dwarfed than when growing naturally on their own roots. Figs. 3, 4 and 5, showing Yellow Egg (Pershore) on Myrobolan B, on Common Plum and upon its own roots, illustrate this very well. Whilst it is impossible to predict what will happen eventually to these trees, especially since ultimate cropping performance is bound to reflect itself in total " vigour ", the first series of trees, though a small and ill prepared one, shows that at the end of thirteen years Yellow Egg trees grafted on Myrobolan seedlings were very definitely more vigorous than those left to grow upon their own roots.

TABLE IX.

Comparison of Yellow Egg (Pershore) upon own roots and grafted upon various stocks. (Planted 1921—*grubbed December* 1932. *Thirteen years.)*

	No. of Trees.		Area Cross Section of Stem in sq. cms. 1932.	Head of Tree Height and Spread in metres.		Wood Growth 1921-24. cms.	Total Weight in kilos. 1932.	Fruit to	
	1921.	1932.						1929.	1932 only.
On Myrobolan (Seedlings)	8	7	148	3·8	4·6	44·0	70·0	41·8	61·7
On Own Roots	10	9	98	3·2	3·8	45·4	45·9	46·8	49·1
On St. Julien (Seedlings)	8	7	107	3·0	4·3	35·5	47·2	32·2	45·9
On Pershore (Suckers)	10	9	93	2·6	3·9	46·0	40·4	51·3	48·6
On Common Plum (Layers)	7	7	62	2·8	3·4	33·4	31·8	43·6	33·6

The above series of trees were not ideal for experimental purposes for several reasons. The rootstocks were bought in from several sources and some had been raised, as indicated, by seedlings and others vegetatively propagated. Again, the own root trees, instead of being cut back at the time the other stocks were grafted with Yellow Egg, were allowed to make natural heads without this initial hard cutting. However, since the figures so clearly confirm the younger and more carefully executed series, it seems likely that they will foreshadow the course of events in this latter series. The comparison of total weights of trees at the time of grubbing falls strikingly into line with the records for area of cross section of stem for the same trees. This latter record must at the moment be relied upon as a true expression of vigour in the youngest series of trees.

It cannot be argued that the trees on Myrobolan are more vigorous merely because they are on seedling roots in this case, because the St. Julien stocks were also seedlings and do not exhibit a greater degree of vigour.

Unfortunately, owing to pressure of recording work, there was a break of two important years—1930 and 1931—in the cropping records. Although the total crops to the end of 1929 suggest no striking differences, the crop weights recorded in 1932 indicate that an altered position had come about. The slower cropping trees on Myrobolan, which previously had a total equal to that on the quick cropping Common Plum, in 1932 bore approximately double the weight of fruit of the latter (61·7 : 33·6 kilos.). This is undoubtedly the result of the much bigger bearing area of the larger trees, though the crop is still slightly lighter per unit of wood growth as expressed by total weight of tree. There is also a similar proportionately heavy increment in fruit crop from the trees growing on their own roots, and there is no doubt that in all cases the vigour will be slowed down as a result, but, if it is allowable to take the behaviour of apples as an analogy, there is no evidence of any " evening up " in growth of trees on various root systems even when they all reach " maturity ".

The crops upon the series of nine year old trees have so far been small, especially on Victoria and Cambridge Gage, where they have certainly been insufficient to have much effect on vigour. However there is in the striking case of Victoria, a suggestion that some varieties may crop better and in the case of Yellow Egg at least as well on their own roots in the early years, although there is every indication that eventually size may prove to be a decisive factor in the ultimate total crop of the tree.

One series of trees, the second, planted in 1924, was especially designed to investigate whether a rootstock already proved to give prolific crops in the early years, such as the Common Mussel, could hasten the productive period of a number of varieties commonly grown upon their own roots. Table X summarizes the results.

Four of the six varieties made strikingly more wood growth, the year after transplanting, on Common Mussel, but by the end of twelve years the thickness of their trunks suggests that the trees of Cambridge Gage, Bastard Victoria, Warwick Drooper and Kea Damson on their own roots have caught up or surpassed those on Mussel. Whilst Blaisdon Red on its own roots has proved the more vigorous, the Yellow Egg trees on Common Mussel have grown more rapidly, though in Series 3 these latter as yet show no significant difference. The measurements of height and spread of head suggest that, as is so often the case, the trees on their own roots are, for the most part, slightly more upright.

The smaller trees of Yellow Egg and Warwick Drooper on their own roots and of Bastard Victoria on Common Mussel have cropped respectively heavier for size of tree than their companions, but there is nothing in the total crop figures to suggest that Common Mussel has in general materially altered the productiveness of these varieties. In only one case, Blaisdon Red, have the budded trees shown any signs of earlier bearing.

TABLE X.

Comparison of local varieties of Plum on own roots and budded on Common Mussel. (Planted 1924 as two year olds. Twelve years old.)

	No. of Trees.	Wood Growth 1924-25. metres.	Area Cross Section of Stem in sq. cms. 1934.	Fruit in kilos. to 1934.
CAMBRIDGE GAGE.				
On Own Roots	5	504	220·9	54·9
Common Mussel	5	762	222·5	54·9
YELLOW EGG.				
On Own Roots	7	784	106·6	157·1
Common Mussel	7	703	128·0	142·1
BASTARD VICTORIA.				
On Own Roots	5*	693	119·4	120·8
Common Mussel	5*	847	98·6	122·1
WARWICK DROOPER.				
On Own Roots	10	915	137·9	203·8
Common Mussel	10*	1,074	140·1	179·3
BLAISDON RED.				
On Own Roots	5	875	172·2	101·2
Common Mussel	5	854	164·5	104·9
KEA DAMSON.				
On Own Roots	5	765	148·0	78·1
Common Mussel	5	987	127·2	69·9

* One tree killed by Bacterial Dieback.

Whilst these three series of trees, planted over a fifteen year period, do demonstrate that it is possible, at least within a limited range of varieties, to grow and crop certain plums on their own roots as successfully as when budded upon extraneous rootstocks, it would not be safe at this juncture to agree that the principle should be applied more widely even to varieties which propagate readily by vegetative methods. It would appear that the response of each individual variety would require individual study.

From the theoretical point of view it is interesting to note that over a period of thirteen years it has been possible to increase the vigour of one variety—Yellow Egg—beyond its "normal" behaviour on its own roots, and over a period of nine years to produce the same effect upon other varieties—Cambridge Gage and Cluster Damson. Whether these own root trees ultimately catch up to those on Myrobolan in vigour remains to be seen.

MAIN ROOTSTOCK TRIALS.

In the first progress report (1) it was possible to present considerable evidence with regard to the comparative vigour likely to be induced by the use of certain rootstocks. As the trees had as yet borne only very small crops, it was not possible to draw any very definite conclusions with regard to rootstock effect upon productivity, though the amount of blossom, the actual number of flowers per spur and the percentage of flowers setting had yielded suggestive indications.

The oldest series of trees (Plot 20), some four hundred and sixty-four in all, had to be grubbed four years later (1932) to make room for an interplanted experiment of bush pears, for the benefit of which they had been rather severely cut back for some seasons previously. This rendered the value of subsequent crop weights very doubtful, so that unfortunately in the pressure of recording these were not kept for two years. However these trees afforded a valuable opportunity for obtaining some rough data of total tree weight and so were grubbed with considerable care. A report on the character of the developed root systems of these trees has already appeared (7).

The second and main series of trees (Plot 21), consisting of some two hundred trees of three varieties—Victoria, Rivers' Early Prolific and President upon eight different rootstocks, Myrobolan B, Marianna, Brompton, Brussels, Common Mussel, Broad Leaved Mussel, Pershore (Yellow Egg) and Common Plum—is now fourteen years old. As the first and most complete comparison of varieties budded upon this series of rootstocks which had all been raised by layering methods, it is especially important, and has yielded valuable evidence with regard to the effect of the various stocks upon both vigour and cropping.

Finally a third series—now eleven years old—which included Czar on the same eight rootstocks, Purple Egg on five and Utility on three, was planted in 1926.

It is proposed to present the figures for the main series first and to use the records upon the earlier and later ones to demonstrate where these results are confirmed and how far they need qualification.

ROOTSTOCK EFFECT UPON VIGOUR.

The area of the cross section of the trunk calculated from an annual girth measurement at a given point is the most complete record available, since measurements of new wood growth had to be abandoned in 1925. The following Table shows the position of this main series.

The three scion varieties were well chosen in that President is normally of very vigorous growth, Victoria intermediate and Early Prolific somewhat slow. It will be noted that in all three cases the trees on Myrobolan B stand in a group to themselves as the most vigorous, yet whilst the Presidents on this stock have nearly three times the cross section of the most dwarfed trees (on Common Plum), the Victoria on Myrobolan B have just over double stem thickness of the dwarfest trees (on Broad Leaved Mussel), whilst the thickest stemmed Prolifics are barely twice as large as those of the dwarfest trees (on Pershore).

TABLE XI.

Comparisons of areas of cross sections of stem of Plums on various rootstocks. (*Plot* 21—*planted as two year olds in* 1922. *Now fourteen years old.*)

	VICTORIA.				PRESIDENT.				RIVERS' EARLY PROLIFIC.			
	No. of Trees. 1922.	1934.	sq. cms.	Order.	No. of Trees. 1922.	1934.	sq. cms.	Order.	No. of Trees. 1922.	1934.	sq. cms.	Order.
Myrobolan B ..	9	6	184·3	(1)	12	11	329·7	(1)	11	11	143·2	(1)
Brompton ..	10	7	162·3	(2)	12	11	257·2	(3)	11	11	114·9	(4)
Broad Leaved Mussel ..	10	7	85·7*	(8)	12	12	260·0	(2)	11	11	117·8	(3)
Marianna ..	12	10	115·1†	(4)	8	7	245·5	(5)	10	9	129·5	(2)
Pershore ..	10	5	97·5*	(6)	12	10	254·1	(4)	11	11	83·0	(8)
Common Mussel	11	5	101·2*	(5)	12	12	199·9	(6)	11	11	90·5	(7)
Brussels ..	10	5	121·6†	(3)	11	4	159·8	(7)	11	11	91·9	(6)
Common Plum ..	11	5	96·9*	(7)	8	3	127·6	(8)	11	11	95·9	(5)

* No significant difference between these.

† No significant difference between these.

In two out of the three comparisons (Victoria and President) the trees on Common Plum are amongst the most dwarfed, and even in the case of Early Prolific the trees on this stock are very near the lowest group.

The trees on Brompton in all three cases are vigorous; in the case of Victoria they take second place, whilst in the other two they are bracketed with several other stocks in the same situation.

It is evident that certain varieties show preferences for Broad Leaved Mussel, which with President and Prolific gives vigorous trees, yet with Victoria it produces ones which fall into the most dwarfed group. The experience of a recent gale suggests that there may be some form of latent incompatibility in this latter case. Marianna has tended to produce trees with stout stems in all cases. The Pershore (Yellow Egg) stock shows considerable variability, for whilst it produces trees of medium size, this varies from distinctly dwarfing in the case of Prolific, to almost vigorous in the case of President. The trees on

Common Mussel are usually closely associated with those on Pershore, though in the case of President, the trees on this stock form a significantly less vigorous group to themselves. In the same way the trees on Brussels and Common Plum are usually bracketed at the bottom of the list, yet in the case of Victoria the trees on Brussels are considerably more vigorous and are bracketed with those on Marianna.

The younger series of trees, whilst confirming these most outstanding results, shows in the following Table that other varieties have similar preferences.

TABLE XII.

Comparisons of areas of cross sections of stem of Plums on various rootstocks.
(*Plot* 29—*planted as two year olds in* 1926. *Now eleven years old.*)

	CZAR.			PURPLE EGG.			UTILITY.		
	No. of Trees.	sq. cms.	Order.	No. of Trees.	sq. cms.	Order.	No. of Trees.	sq. cms.	Order.
Myrobolan B ..	9	90·6	(1)	8	113·7	(1)	12	244·3	(1)
Broad Leaved Mussel ..	12	70·9	(2)						
Common Mussel ..	12	70·1	(3)	8	70·2†	(2)			
Brompton ..	10	67·5	(4)						
Pershore ..	7	67·4	(5)						
Marianna ..	6	63·2	(6)	6	58·3*	(4)	6	139·2	(3)
Brussels ..	7	51·0	(7)	8	65·4*†	(3)			
Common Plum ..	12	40·6	(8)	8	56·2*	(5)	9	145·7	(2)

* No significant difference between these.

† No significant difference between these.

The trees of all three varieties on Myrobolan B once again are significantly the most vigorous, but it is interesting to note that here it is the more slow growing scions, Czar and Purple Egg, which are more invigorated than the naturally sturdy growing Utility. Again, the trees on Common Plum in each case come amongst the most dwarfed. However, Czar on Common Mussel appears stouter stemmed and on Marianna less vigorous than would be anticipated from the performance of other varieties in the earlier table. Purple Egg is also more vigorous on Brussels and Utility less vigorous on Marianna than might have been predicted.

The extremes of vigour at present obtainable is well illustrated in Figs. 1 and 2 which show typical Victoria Plum trees upon Myrobolan B and Common Plum rootstocks and in Figs. 6 and 7 which show the contrast between the variety Czar upon Myrobolan B and Brussels stock.

In the light of these two field experiments it is worth examining the final records taken upon the original large, though incomplete, series of trees which afforded most of the data for the first progress report. It will be remembered

TABLE XIII.

Comparisons of areas of cross sections of stem and total tree weight of six varieties when grubbed at thirteen years, 1932. (Plot 20.)

	VICTORIA.		CZAR.		YELLOW EGG.		BELLE DE LOUVAIN.		DENNISTON'S GAGE.		GIANT PRUNE.	
	Area Cross Section. sq. cms.	Total Tree Weight. kilos.	Area Cross Section. sq. cms.	Total Tree Weight. kilos.	Area Cross Section. sq. cms.	Total Tree Weight. kilos.	Area Cross Section. sq. cms.	Total Tree Weight. kilos.	Area Cross Section. sq. cms.	Total Tree Weight. kilos.	Area Cross Section. sq. cms.	Total Tree Weight. kilos.
Myrobolan (Seedlings)	147*	73·1	141	77·2	148	70·8	215	123·5	241	138·5	—	—
Brompton	123	55·8	96	55·8	111	49·9	205	106·2	219	126·7	98	43·1
Broad Leaved Mussel	—	—	—	—	70	31·8	—	—	—	—	—	—
St. Julien (Seedlings)	101	44·9	119	68·1	107	47·2	198	104·9	187	108·5	94	47·7
Pershore	95	51·3	81	41·3	93	40·4	131	71·7	139	80·8	64*	36·3
Common Mussel	80	24·5	82	36·8	—	—	—	—	—	—	—	—
Brussels	95	42·2	82	44·0	86	36·8	118	60·8	126	71·7	86	38·6
Common Plum	85	41·3	48*	Not recorded.	62	31·8	141	75·4	143	84·0	—	—

* Less than three trees were available for grubbing eventually.

that a wide range of scions, including at least three species of plum, Cerasifera (Myrobolan), Insititia (Prune Damson) and Domestica (seven representative varieties) were used upon such stocks as were available in 1920. The limitations of this material and its lay-out have been fully discussed elsewhere, but the final girth measurements which enable the areas of cross section of stem to be worked out, and the total weight of the tree's "carcass" (minus roots) fall in line most definitely with the later and more accurate experiments, as Tables XIII and XIV show.

TABLE XIV.

Comparisons of areas of cross sections of stem and total tree weight of four further varieties on smaller range of stocks when grubbed at thirteen years, 1932. (*Plot* 20.)

	PURPLE EGG.		PRUNE DAMSON.		BLACK BULLACE.		CHERRY PLUM* (Myrobolan).	
	Area Cross Section. sq. cms.	Total Tree Weight. kilos.	Area Cross Section. sq. cms.	Total Tree Weight. kilos.	Area Cross Section. sq. cms.	Total Tree Weight. kilos.	Area Cross Section. sq. cms.	Total Tree Weight. kilos.
Myrobolan (Seedlings) ..	—	—	169	100·8	116	89·9	287	—
Brompton ..	105	56·3	—	—	95	63·6	223	—
Pershore ..	73	38·1	127	73·1	75	49·5	201	—
St. Julien (Seedlings) ..	—	—	132	76·3	89	59·5	236	—
Brussels ..	60	29·5	—	—	—	—	172	—

* These trees were not grubbed, but were left as wind breaks.

In the eight cases in which trees were worked on Myrobolan (Seedlings) they were invariably the heaviest and stoutest stemmed—even, it is interesting to note, where Red Cherry Plum, a scion of the same species, is used. In nearly all cases, the trees on Myrobolan are approximately twice the weight of the smallest group in each series. Brompton is used in nine combinations and though always proving less vigorous than Myrobolan, almost invariably comes a good second on the list. It is worth remembering here that this is a vegetatively propagated stock, yet in seven comparisons out of eight it has given stouter, heavier trees than the St. Julien seedlings. This seems to suggest that the supposedly inherent vigour of the "seedling" as compared with the layer may be over-rated. In six combinations trees on Brussels have given the smallest trees, and in three those on Common Plum have behaved likewise. Except in the case of Giant Prune, where only one tree remained, Pershore has always produced trees of intermediate vigour.

If these total tree weights be compared with the areas of cross section of stem in 1932, it will be agreed that this latter measure of vigour is certainly likely to give a sufficiently accurate picture of the trees' vigour until such time as they can be lifted and weighed.

Two further series of trees planted to elucidate other aspects of the rootstock problem and dealt with under other sections of this paper (viz. the first and third series in which budded trees are compared with those on their own roots—Tables VIII and IX), go to confirm the general deductions with regard to the universally vigorous influence which Myrobolan B has upon a wide range of scion varieties, and likewise the restraining influence of Common Plum.

Rootstock Effect upon Cropping.

It will be recalled that in the first progress report the effect of rootstock upon the number of spurs—both fruiting and infertile—and the average number of flowers per bud, were dealt with in some detail as being the chief indications in the young trees of future productivity. Generally speaking, trees on Pershore, Common Mussel and Common Plum had the highest percentage of short fertile spurs, whilst those on Brussels, Brompton and Myrobolan produced longer and infertile ones. The former actually possessed more flowers per bud and more buds per spur than the latter. This indication of early productivity was largely borne out by the actual number of fruits carried during the first four years by the oldest series of trees. Although there have been several very unfortunate seasons (notably 1925, 1927, 1928, 1933 and 1935 (8)) for the setting of plum blossom in general at East Malling, there have been some heavy crops since 1927, so it is now possible to present considerable data to show how far these early indications have been confirmed or contradicted as the trees became mature in the successional plantings.

As usual, cropping must be considered from three points of view. First, the earliness of coming into bearing ; secondly the total crop per tree over a given period or the full life of the tree ; and third, the yield per acre which would have been obtained if size of tree had been intelligently understood in the scheme of planting.

Earliness of Coming into Bearing.

Tables XV, XVI, XVII and XVIII show the accumulated crops for the different scion-rootstock combinations of Series 2 (Plot 21) and Series 3 (Plot 29).

As will be seen there are marked differences in earliness of bearing. The most striking rootstock in this respect is Marianna, which is on the whole unsurpassed both for precocity and continuous heavy cropping for its size.

With Victoria, up to the eighth year, the trees on this stock had yielded nearly three times the crop of those on any other stock. In the ninth year their total was approached by the trees on Myrobolan B which had a heavy crop in this season. However with the exception of a single year (1931) when these trees on Marianna had a complete "off" season, they have maintained their lead right up to the present day.

TABLE XV.

Accumulated crops in kilograms per tree of Victoria on different rootstocks from the sixth to the fourteenth year.

	1924-26.	1927.	1928.	1929.	1930.	1931.	1932.	1933.	1934.
Myrobolan B* ..	0·1	0·4	1·7	32·2	88·3	**112·5**	126·0	139·3	206·1
Brompton ..	0·2	0·3	1·5	8·2	66·0	76·3	90·0	100·5	155·2
Brussels ..	0·1	0·1	1·5	10·3	42·7	54·6	59·6	71·4	117·8
Marianna ..	**2·9**	**3·8**	**17·7**	**40·0**	**97·6**	99·1	**152·9**	**176·9**	**240·8**
Common Mussel ..	0·3	0·3	6·2	11·2	40·1	48·5	61·6	74·3	112·3
Pershore ..	0·4	0·6	3·8	17·3	54·3	67·0	97·4	124·2	157·2
Common Plum ..	0·2	0·6	2·9	11·2	50·9	53·2	61·8	70·8	115·1
Broad Leaved Mussel ..	0·1	0·2	2·7	6·2	39·1	47·8	59·2	82·0	107·0

* Stocks arranged in order of vigour.

TABLE XVI.

Accumulated crops in kilograms per tree of Rivers' Early Prolific on different rootstocks from the eighth to the fourteenth year.

	1924-28.	1929.	1930.	1931.	1932.	1933.	1934.
Myrobolan B*	0·1	0·7	31·5	46·9	69·0	93·7	**121·1**
Marianna	**0·4**	**2·5**	**34·5**	**50·1**	**73·9**	**95·9**	119·2
Broad Leaved Mussel ..	0·2	0·7	33·0	44·1	68·6	84·5	106·3
Brompton	0·1	0·7	24·9	32·1	49·7	57·1	74·6
Common Plum	0·2	1·5	21·2	34·4	51·1	66·1	81·4
Brussels	0·1	0·4	16·1	22·0	33·3	38·8	49·9
Common Mussel	0·1	0·5	21·2	29·3	48·6	57·3	77·0
Pershore	0·1	1·6	14·1	24·2	38·5	46·5	64·2

* Stocks arranged in order of vigour.

TABLE XVII.

Accumulated crops in kilograms per tree of President on different rootstocks from the sixth to the fourteenth year.

	1924-26.	1927.	1928.	1929.	1930.	1931.	1932.	1933.	1934.
Myrobolan B ..	0·1	0·1	0·3	1·0	8·6	14·2	24·4	**118·3**	**130·1**
Broad Leaved Mussel ..	0·1	0·1	0·3	1·6	5·8	8·8	17·1	79·2	88·5
Brompton ..	0·3	0·5	0·8	2·1	11·2	14·0	24·2	96·2	103·3
Pershore ..	0·3	0·6	0·9	**2·8**	6·3	8·4	19·1	117·9	127·4
Marianna ..	**0·5**	**1·2**	**1·4**	1·8	**14·8**	**19·5**	**32·3**	115·0	121·6
Common Mussel ..	0·2	0·3	0·5	1·9	5·7	8·0	18·0	68·1	74·7
Brussels ..	0·2	0·2	0·3	1·5	3·9	5·8	10·2	40·6	45·1
Common Plum ..	0·3	0·5	0·5	1·7	3·5	5·4	12·6	84·5	90·7

TABLE XVIII.

Accumulated crops in kilograms per tree of Czar, Purple Egg and Utility on different rootstocks from the seventh to the eleventh year.

	1926-30.	1931.	1932.	1933.	1934.
CZAR.					
Myrobolan B* ..	2·3	16·7	34·1	61·0	**91·9**
Broad Leaved Mussel	2·8	14·9	29·0	52·6	72·6
Common Mussel ..	2·4	15·5	31·6	47·3	67·3
Brompton	1·7	18·0	34·1	54·0	74·1
Pershore	2·2	22·8	36·2	**66·3**	89·2
Marianna	3·7	**23·5**	**49·0**	62·2	84·1
Brussels	1·7	12·2	25·3	40·0	52·3
Common Plum ..	**4·4**	11·5	29·4	39·2	51·6
PURPLE EGG.					
Myrobolan B ..	1·5	17·5	31·5	**74·8**	**122·8**
Common Mussel ..	0·9	14·3	25·9	50·1	74·7
Brussels	0·3	9·3	17·6	40·1	56·5
Marianna	1·4	20·1	**32·5**	64·0	90·0
Common Plum ..	**1·7**	**20·3**	31·5	63·4	87·8
UTILITY.					
Myrobolan B ..	0·2	1·5	2·4	6·8	19·2
Marianna	0·4	2·1	2·6	3·4	13·8
Common Plum ..	**0·5**	**2·9**	**5·8**	**9·9**	**19·8**

* Rootstocks arranged in order of vigour.

The only other stocks to show any tendency to hasten the bearing of Victoria were Common Mussel and Pershore, but they were easily surpassed by the trees on Myrobolan B in the ninth season.

With Rivers' Early Prolific the trees on Marianna again kept the lead right up to the fourteenth season, when they were overtaken by those on Myrobolan B. However, with this slower cropping variety the advantage in early cropping is not marked, and the record of the trees on Marianna was closely approached by those on Myrobolan B and Broad Leaved Mussel in the tenth season—the first in which there was an appreciable crop.

Although very small crops were harvested, the trees of President on Marianna were again pre-eminent up to the twelfth season, being only surpassed temporarily by those on Pershore in the ninth. The first and only year of heavy cropping was 1933 (the thirteenth) and in this year the trees on Myrobolan B took first place.

The trees on Pershore, after losing their lead in the tenth year, did not do so well for the next two seasons, but regained second place in 1933.

With the earlier cropping Czar the trees on Common Plum had cropped slightly more heavily than those on Marianna up to the seventh year, but for the next two seasons trees on the latter stock were again in the lead. In the tenth year their crop was exceeded by the trees on Pershore ; but in the eleventh season the trees of Myrobolan passed them both.

With the variety Purple Egg the actual crops per tree from the seventh to the ninth year were very alike on Common Plum, Marianna and Myrobolan B. The last rootstock, however, went ahead in the tenth and eleventh years.

So little fruit has been yielded by the variety Utility, on the three stocks included, that there is little evidence of early bearing to be seen. However up to the eleventh year the trees on Common Plum have yielded slightly more than the other two throughout.

It was obviously only a matter of time before the long infertile spurs originally described upon the young trees of Victoria upon Myrobolan and Brompton developed fruit buds, and that this additional potential bearing area must eventually be of advantage to the tree. This is well shown when the total cropping to date for the different series is examined.

TOTAL CROP PER TREE.

Tables XIX and XX give the average total crop per tree for the main series of trees, now fourteen years old and for the third series, now eleven years old. Whilst it is obvious that, to some degree, amount of potential bearing area is influencing total crop, there are a number of obvious exceptions which suggest that rootstock preferences are still a deciding factor. Though with all six varieties the trees on Myrobolan B are at, or near, the head of the list, those on Brompton in four out of five comparisons, and on Broad Leaved Mussel in three out of four, are cropping poorly for size of tree. Only in combination with Rivers' Early Prolific does the last mentioned show to advantage. Trees on Pershore and Marianna are, on the other hand, generally outstandingly high in crop considering the average size of tree. Trees on Common Mussel, Brussels and Common Plum are generally to be found not far apart towards the bottom of the list, though there are notable exceptions, as in the case of Rivers' Early Prolific, where trees on Common Plum have cropped significantly heavier than those on Pershore and those on Common Mussel are bracketed with them. Also Purple Egg on Common Plum are bracketed with Marianna and Common Mussel, being significantly heavier cropping than on Brussels. Even when creditable trees developed on Brussels stock—as in the case of Victoria and Purple Egg—the resulting crops appear disappointing. Common Plum on the other hand is usually towards the bottom of the list solely because of the size of the tree. Trees of Victoria, President and Czar on Common Mussel have certainly proved disappointing in not maintaining heavy crops in relation to tree size. In five instances out of six, the results obtained by the use of Marianna are encouraging, especially since the trees are by no means always excessively vigorous.

TABLE XIX.

Comparison of total cropping of Plums on various rootstocks. (Plot 21, planted as two year olds in 1922—fourteen years old.)

VICTORIA.			PRESIDENT.			RIVERS' EARLY PROLIFIC.		
	Fruit in kilos.	Order by vigour.		Fruit in kilos.	Order by vigour.		Fruit in kilos.	Order by vigour.
On Marianna	241	4	On Myrobolan B	130	1	On Myrobolan B	121	1
Myrobolan B	206	1	Pershore	127	4	Marianna	119	2
Pershore	157	6	Marianna	122	5	Broad Leaved Mussel	106	3
Brompton	155	2	Brompton	103	3	Common Plum	81	5
Brussels	118	3	Common Plum	91	8	Common Mussel	77	7
Common Plum	115	7	Broad Leaved Mussel	88	2	Brompton	75	4
Common Mussel	112	5	Common Mussel	74	6	Pershore	64	8
Broad Leaved Mussel	107	8	Brussels	45	7	Brussels	50	6

TABLE XX.

Comparison of total cropping of Plums on various rootstocks. (Plot 29, planted as two year olds, 1926—eleven years old.)

CZAR.			PURPLE EGG.			UTILITY.		
	Fruit in kilos.	Order by vigour.		Fruit in kilos.	Order by vigour.		Fruit in kilos.	Order by vigour.
On Myrobolan B	91·9	1	On Myrobolan B	122·8	1	On Common Plum	19·8	2
Pershore	89·2	5	Marianna	90·0	4	Myrobolan B	19·3	1
Marianna	84·1	6	Common Plum	87·8	5	Marianna	13·8	3
Brompton	74·1	4	Common Mussel	74·7	2			
Broad Leaved Mussel	72·6	2	Brussels	56·5	3			
Common Mussel	67·3	3						
Brussels	52·3	7						
Common Plum	51·6	8						

TABLE XXI.

Comparison of recorded total crop weights of five varieties of Plum on eight different rootstocks. (Plot 20, grubbed at thirteen years. Eleventh and twelfth years' crop records not available.)

VICTORIA.			CZAR.			YELLOW EGG.			BELLE DE LOUVAIN.			DENNISTON'S GAGE.		
	Kilos.	Order by vigour.		Kilos.	Order by vigour.		Kilos.	Order by vigour.		Kilos.	Order by vigour.		Kilos.	Order by vigour.
Myrobolan (Seedlings)	122·5	1	Myrobolan (Seedlings)	109·8	1	Myrobolan (Seedlings)	103·5	1	Brompton	82·7	2	Pershore	53·5	5
Brompton	106·2	2	Brompton	92·6	3	Pershore	99·9	4	St. Julien (Seedlings)	51·3	3	Brompton	46·3	2
Pershore	89·4	3	Pershore	88·1	5	Brompton	91·7	2	Myrobolan (Seedlings)	47·6	1	Common Plum	43·6	4
Common Plum	85·4	6	St. Julien (Seedlings)	83·9	2	Brussels	80·8	5	Common Plum	43·6	4	St. Julien (Seedlings)	35·0	3
Brussels	68·1	5	Common Mussel	79·0	6	St. Julien (Seedlings)	78·1	3	Pershore	36·4	5	Myrobolan (Seedlings)	27·2	1
St. Julien (Seedlings)	60·4	4	Common Plum	45·0	7	Common Plum	76·7	6	Brussels	28·6	6	Brussels	20·9	6
Common Mussel	59·5	7	Brussels	No final record.		Broad Leaved Mussel	65·0	6						

TABLE XXII.

Comparison of recorded total crop weights of five varieties of Plum on four different rootstocks. (Plot 20, grubbed at thirteen years. Eleventh and twelfth years' crop records not available.)

GIANT PRUNE.			PURPLE EGG.			PRUNE DAMSON.			BLACK BULLACE.			RED CHERRY PLUM.		
	Kilos.	Order by vigour.		Kilos.	Order by vigour.		Kilos.	Order by vigour.		Kilos.	Order by vigour.		Kilos.	Order by vigour.
Pershore	136·2	4	Brompton	68·5	1	Myrobolan (Seedlings)	11·8	1	Pershore	56·0	4	Pershore	111·9	4
Brompton	126·2	2	Pershore	66·4	2	Pershore	6·7	3	Myrobolan (Seedlings)	48·7	1	Brompton	88·0	3
Brussels	110·8	3	Brussels	33·1	3	St. Julien (Seedlings)	6·9	2	Brompton	46·0	2	St. Julien (Seedlings)	85·2	2
St. Julien (Seedlings)	102·6	1							St. Julien (Seedlings)	41·9	3	Myrobolan (Seedlings)	70·8	1
												Brussels	51·7	5

Although the hard cutting treatment and the abandonment of recording on the original trees (Series 1) during 1930 and 1931—which were two important years from the cropping point of view—unfortunately leave the history incomplete, the total crops up to 1930 and the final one harvested in 1932, so generally confirm the deductions made from the later series of trees that they are summarized in Tables XXI and XXII.

Though the trees on Myrobolan (Seedling) once more generally take the lead in the matter of crop, closely followed by those on Pershore, there are two instances—those of Denniston's Gage and the Red Cherry Plum—in which the trees on Pershore take a remarkable lead despite their greatly inferior vigour.

The performance of all varieties on Brompton in this first planting, in most cases not differing very widely from that on Myrobolan, is a confirmation of the results with Victoria and Czar in the later series. Belle de Louvain, Denniston's Gage, Purple Egg, Giant Prune and Red Cherry Plum all seem to have been particularly successful upon this stock.

As will be seen from Tables XIX to XXII, the magnitude of the crop differences are quite important. Victoria on Marianna has given more than twice the weight of fruit of the trees on Brussels, Common Plum and the Common and Broad Leaved Mussels. Purple Egg on Myrobolan B has behaved similarly in relation to the trees on Common Plum. President on Myrobolan B has given crops approaching three times those harvested off the trees on Brussels.

Unfortunately, the incompleteness of the fruit data renders it impossible to draw any conclusions as to total weight of tree in relation to total weight of crop from the grubbed series.

CROP PER ACRE.

The practical aspect of the problem demands that the question of crop per acre should be considered and principally for this reason a record of the average height of the head and spread of branches in two directions is made periodically. Table XXIII gives these data for the main series of trees.

These measurements, although admittedly rather rough, not only suggest the practical consideration of the most suitable and economic distance at which to plant a variety on any particular rootstock, but they also suggest that rootstock does, even in the later years, maintain its influence in some degree upon the shape of the tree.

The later planting of Czars varied from 4·2 metres spread on Myrobolan B to 3 metres on Common Plum and Brussels. The Purple Egg varied from a spread of 4·4 metres on Myrobolan B to 3·9 metres on Marianna and Brussels, whilst the extremes in the case of Utility were 5·4 metres on Myrobolan B and 4·5 metres on Common Plum. Based upon these measurements, it would be possible to draw up a table suggesting suitable distances for planting and

TABLE XXIII.

	VICTORIA.		PRESIDENT.		RIVERS' EARLY PROLIFIC.	
	Spread.	Height.	Spread.	Height.	Spread.	Height.
	Metres.		Metres.		Metres.	
Myrobolan B ..	5·2	3·3	5·6	4·4	5·0	3·7
Brompton	4·8	3·2	4·6	4·1	4·3	3·3
Marianna	4·5	2·8	4·6	3·8	4·9	3·1
Common Plum ..	4·5	3·1	4·2	3·1	4·4	2·9
Brussels	4·4	3·0	3·3	3·4	4·2	2·9
Common Mussel ..	4·3	2·8	4·4	3·7	4·5	3·1
Pershore	4·2	2·6	4·9	3·8	4·4	2·8
Broad Leaved Mussel	4·1	2·8	4·7	4·2	4·6	3·2

calculating at various periods in the tree's life the crop per acre which might reasonably be expected. In Table XXIV the variety Victoria (Plot 21) is taken as an example.

EFFECT ON FRUIT SIZE AND TIME OF RIPENING.

For the reasons already mentioned—the normal methods of "picking over" the plum crop during a period of days instead of stripping the trees at a single harvesting—it has been difficult to collect any very reliable data on fruit size and quality, though numerous attempts have been made from time to time.

In the first few years the fruits on Myrobolan Seedlings were of poor size and appearance compared with the quicker cropping trees on Common Mussel and Pershore; but as the trees came into heavy bearing the fewer fruits on the more vigorous stocks had the advantage, and were often obviously the largest since they were well placed without competition as if they had been thinned.

TABLE XXIV.

Calculations showing crop per acre of trees suitably planted according to spread of branches.

Stock.	Distance apart. ft.	Trees per acre.	6 years crop per acre. cwts.	12 years crop per acre. tons.
Myrobolan B	18	134	5	27
Brompton	17	152	5	23
Marianna	16	170	59	40¼
Common Plum	16	170	10	19¼
	15	193	11	21¾
Brussels	15	193	6	22½
Common Mussel	15	193	23	21¼
Pershore	14	222	16	34¼
Broad Leaved Mussel ..	14	222	12	23¼

Again, these differences have undoubtedly varied from season to season and according to whether particular trees are bearing heavily or not.

Over the whole period of cropping it has been impossible to detect any consistent differences in the case either of Victoria or President in the main series. In the case of Rivers' Early Prolific, on the other hand, there were quite striking differences in fruit size in two years of moderate cropping. The extremes are shown in Table XXV ; as will be seen, in spite of a much larger crop the fruit on Marianna was considerably bigger than on Brussels.

TABLE XXV.

Mean number of fruits per kilo. of Rivers' Early Prolific on two rootstocks.

	1930.		1931.	1932.	
	Crop in kilos.	Number per kilo.		Crop in kilos.	Size.
Brussels	15·6	80·8	No size record.	11·4	78·4
Marianna	32·0	66·4		23·9	64·9

The trees on the other varieties of rootstock were in an intermediate position. The records were not repeated after 1932, but they are certainly suggestive.

A similar instance was recorded in comparing the fruits of Warwickshire Drooper from trees on their own roots and on Common Mussel—the figures over a four year period were as follows:

TABLE XXVI.

Comparison of number of fruits per kilo. of Warwickshire Drooper on Own Roots and on Common Mussel.

	1931.	1932.	1933.	1934.	4 years Mean.
From Own Roots	23·8	23·5	27·3	25·5	25·0
From Common Mussel	24·9	26·2	31·3	29·1	27·9

Of equally interesting, and possibly more economic, importance is the influence of rootstock upon time of ripening. Observations were made upon the crop of Czar plums (Plot 29) over a three year period 1932-34.

In 1932 it was found that whilst only 4 per cent. of the total crop on Myrobolan B was fit for harvesting, 17 per cent. of that on Brussels was ready at the first picking. Again, at the last picking, 20 per cent. of the crop from the trees on Myrobolan B remained to be harvested, compared with 2 per cent. from those on Brussels.

These observations were extended in the two following years with the following interesting results:

TABLE XXVII.

Comparison of time of ripening of Czar plums on Brussels and different Myrobolan rootstocks.

Stock.	Mean crop per tree in kilos.	1933.					Mean crop per tree in kilos.	1934.		
		Percentage of total crop.						Percentage of total crop.		
		1st picking.	2nd picking.	3rd picking.	4th picking.	5th picking.		1st picking.	2nd picking.	3rd picking.
Brussels ..	19·9	10	14	31	26	19	12·3	41	55	4
Myrobolan A	21·0	2	6	16	16	61	16·7	18	56	26
,, B	26·9	2	25	28	20	26	30·9	18	69	13
,, C	14·6	14	23	27	15	22	30·7	11	74	15
,, D	17·7	9	16	22	24	29	33·5	20	56	24

Whilst these figures very generally confirm the observations of 1932, it seems certain that the differences may be more striking in certain seasons and may even possibly be influenced by mean crop weight. However, it is quite clear that the fruit from the trees on Brussels has continued to ripen earlier than those on the Myrobolan selections, and that of these Myrobolan A has produced the most outstanding effect on time of ripening. Growers not infrequently claim that early summer applications of nitrogen delay ripening, and it is suggestive that the most vigorous group of stocks appear to be producing the same effect.

EVALUATION OF ROOTSTOCKS OF LOCAL ORIGIN AND THE DIFFERENT VARIETIES OF MUSSEL.

Although it has proved extremely difficult to know where to draw the line in testing an almost endless series of combinations of stock and scion, the remarkable results obtained by experimenting with the local variety of Worcestershire—the Pershore or Yellow Egg—encouraged the writer to think that local usage might in other cases be based on something more than expediency. For this reason the Blaisdon Red, a very vigorous hardy Gloucestershire plum, the sturdy Cambridge Gage, and the prolific Warwickshire Drooper, were included in a subsidiary rootstock trial.

The value of the different "Mussel" stocks in common circulation in England also required to be ascertained and the three most important—the Common Mussel, the Broad Leaved Shining Mussel and the Narrow Leaved Shining Mussel—were included in the same trial.

Czar, by this time known to be a "good indicator" of rootstock effect, was chosen for the scion and trees worked on Myrobolan B and Common Plum were included as vigorous and dwarfed controls. The following Table gives a summary of the trees' performance (Table XXVIII).

TABLE XXVIII.

Czar plum on various local rootstocks and different varieties of Mussel compared with Myrobolan B and Common Plum. (*Planted* 1926 *at two years old—now eleven years old.*)

	No. of Trees.		Area Cross Section of stem. sq. cms.		Head 1933. Metres.		Total crop in kilos. to 1934.
	1926.	1934.	1928.	1934.	Height.	Spread.	
Myrobolan B	12	9	8·8	90·6	3·1	4·2	91·7
Narrow Leaved Mussel ..	12	12	10·5	72·0	2·6	3·7	75·8
Broad Leaved Mussel ..	12	12	8·6	70·9	2·9	3·8	72·6
Common Mussel ..	12	12	9·1	70·1	2·7	3·8	*67·1
Warwickshire Drooper ..	8	4	10·2	66·6	2·5	3·4	69·4
Cambridge Gage ..	12	7	7·2	62·1	2·4	3·1	50·1
Blaisdon Red	8	8	14·1	59·0	2·6	3·3	*58·1
Common Plum	12	12	8·1	40·6	2·3	3·0	51·3

* These do not differ significantly.

It is obvious that there is nothing outstanding either in vigour or cropping amongst the local varieties tested with Czar, though by now it will be realized that this does not condemn them for other varieties. There is a suggestion that in Cambridge Gage and Czar there may be something of an incompatible nature. It is encouraging to find that the three main varieties of Mussel range themselves so closely together, though the Broad Leaved Mussel has in other trials shown several instances of delayed incompatibility.

Finally, it is interesting to record that under East Malling conditions none of the "local" varieties commonly used as rootstocks have been prolific in throwing up suckers from their own roots. Of these Cambridge Gage has produced the most.

MORTALITY IN TREES DUE TO DISEASE AND DELAYED INCOMPATIBILITY.

Whilst the series of field trials were laid out primarily for the study of rootstock influence upon vigour and cropping, it was always proposed to watch the incidence of any diseases. However, if the devastating effects of Silver Leaf (*Stereum purpurem*) which followed the planting of the first trial and of Bacterial Dieback (*Pseudomonas mors-prunorum*) which decimated the later ones, had been foreseen, it is doubtful whether these large scale trials would have been initiated before these troubles could be controlled with greater confidence.

Perhaps it is as well that they could not be foreseen, since the twelve acres of plum trees have yielded some very suggestive data, both with regard to varietal susceptibility and also the extent of the influence of the rootstock in this connection. Moreover, these plantations have afforded an invaluable observation ground for the pathologists, and in the end sufficient trees on the majority of rootstocks have survived to make possible the elucidation of a number of pomological problems.

Since the first series (Plot 20) offers the widest range of varieties, the records taken in relation to the serious outbreak of Silver Leaf shortly after the first planting and pruning of these trees are worth consideration. Bacterial Dieback only became prevalent on the Station after these trees had reached a considerable age and only a very small proportion of whole trees was affected thereby.

Table XXIX gives the position of the different varieties in relation to Silver Leaf infection.

TABLE XXIX.

Incidence of Silver Leaf—showing mortality and recovery of certain varieties (Plot 20).

Variety.	All Stocks.							
	No. of Trees.	No. never Silvered.	No. Silvered.	Per cent. Silvered.	No. killed.	Still Silvered. 1931.	Re-covered. 1931.	Per cent. Silvered Trees re-covered.
Victoria	88	14	74	84	22	23	29	39
Czar	64	17	47	73	2	8	37	79
Pershore Egg ..	64	17	47	73	2	—	45	96
Purple Egg ..	32	10	22	69	—	3	19	86
Denniston's Gage	45	28	17	38	—	3	14	82
Belle de Louvain	40	8	32	80	3	6	23	72
Giant Prune ..	32	11	21	66	2	2	17	81
Prune Damson	32	25	7	22	—	—	7	100
Myrobolan ..	34	32	2	6	—	—	2	100
Black Bullace ..	31	16	15	48	1	1	13	87

Whilst these figures are based on purely chance infections in the field they do emphasize that varietal resistance to the disease is all important. At the bottom of the list come the Red Cherry Plum (Myrobolan), Prune Damson, Denniston's Gage and Black Bullace, with only 6, 22, 38 and 48 per cent. trees infected, whilst Victoria, Belle de Louvain, Czar, Yellow Egg, Purple Egg and Giant Prune had 84, 80, 73, 73, 69 and 66 per cent. respectively. The number of trees of Victoria which were actually killed by the disease—twenty-two—is outstanding. Czar with eight deaths, and Belle de Louvain with six suffered heavily.

No less interesting are the final observations made in 1931 showing the numbers which still showed Silver Leaf symptoms to an appreciable degree and those which had recovered. Whilst the Red Cherry Plum and Prune

Damson had 100 per cent. recoveries, it is interesting to find that Yellow Egg runs them very close with 96 per cent. recovery. Victoria remains at the bottom of the list with only 39 per cent.

If this outbreak of Silver Leaf be examined from the point of view of the rootstocks upon which the trees were worked there is at least one striking indication which falls into line with the other evidence recently published by Brooks and Brenchley (9). Whilst only 64, 66 and 67 per cent. of the varieties upon Common Mussel, St. Julien (Seedlings) and Myrobolan (Seedlings) recovered, no less than 87 per cent. of the trees on Common Plum returned to normal health. Seventy-seven per cent. of the trees on Yellow Egg (Pershore) also recovered.

In the second series (Plot 21), a sudden outbreak of Bacterial Dieback occurred only two years after planting. This was largely confined to the variety Victoria, of which no less than forty trees died in 1924, eight in 1925, ten in 1926, since when only three trees have died with this disease, one in 1927 and the other two in 1932 and 1934. As was pointed out in an earlier paper (10), it is not possible to connect these infections in any way with rootstock, they are rather positional and varietal, since in every case the disease missed the row of Rivers' Early Prolific and in only two instances were trees of President killed—one in 1926 and one in 1929.

It is at least encouraging to note that the main outbreak appears to occur in the early years of the tree's life, and that if it could be protected through the nursery and subsequent period there should be a considerable chance of reducing the mortality.

Whilst Rivers' Early Prolific has suffered no casualties, President, in addition to the two trees already mentioned, has suffered sixteen casualties. Whilst the cause was unascertainable with certainty, there is every reason to believe from the symptoms manifested that, at least in twelve of these cases, i.e. the trees on Brussels and Common Plum, death was due to delayed incompatibility. Only three trees out of eleven on Brussels and three out of eight on Common Plum still survive and these are outstandingly dwarfed and unthrifty in appearance. From the time of transplanting these trees never made normal growth. The other four deaths, two on Pershore and one each on Brompton and Marianna, are not so easily accounted for, since the two former stocks appear compatible with all varieties so far tested, and the growth of these mature trees appears quite healthy.

Attacks of Silver Leaf have been far less severe in this series (Plot 21) though, after a heavy cropping season when many branches were broken, four trees of Victoria—three on Myrobolan and one on Brussels—succumbed.

After the severe gale in September 1935, one tree of Victoria on Broad Leaved Mussel broke off clear at the union—an interesting case where possibly delayed or partial incompatibility appears upon a fourteen year old tree. This is being investigated further.

The eleven year old planting of Czars on different rootstocks (Plot 29) also suffered severely from Bacterial Dieback in the third, fourth and fifth years after planting. During these years six, four and eight trees were lost from this cause—subsequently only two have suffered in 1932 (after a heavy crop) when there was also one case of Silver Leaf. Ten further trees have died from causes unascertained. The fact that three of them were on Brussels and three on Marianna again suggests delayed incompatibility, but it is curious that during the same period there were no similar losses amongst the twelve dwarfed trees on Common Plum. Again, there is no clear indication that rootstock influence has affected the tree's resistance to Bacterial Dieback, though varietal resistance is again to the fore. None of the trees of Utility or Purple Egg on the same plot have been attacked.

SUCKER GROWTHS FROM THE ROOTS.

As suggested in the first report on these investigations, it is becoming apparent that this habit, objectionable from the grower's point of view, is definitely a varietal one. The figures previously published are very generally borne out by the following census which was made in 1935 on the main series (Plot 21) (Table XXX).

TABLE XXX.

	No. of Trees.	No. suckered.	Mean No. of suckers per tree suckering.	Percentage trees suckering.
Pershore	26	1	3·3	3·8
Brompton	28	1	3·6	3·6
Myrobolan A	7	2	2·0	28·6
,, B	63	13	3·0	20·6
,, C	24	1	1·0	4·2
,, D	5	1	4·0	20·0
Marianna	46	2	2·5	2·2
Broad Leaved Mussel ..	30	19	22·9	63·3
Common Mussel	63	50	26·2	79·4
Common Plum	42	36	21·2	85·7
Brussels	39	39	36·6	100·0

It was previously suggested that individual scion varieties tended to accentuate this habit. This hypothesis is borne out by an examination of the above data for the three main varieties separately. Table XXXI shows the suckering of these varieties on the four rootstocks most liable to the trouble.

It is evident that although there is not a great difference in the percentage of trees which sucker, the number of suckers per tree is much less with Rivers'

Early Prolific than with the other two varieties. President appears to be more prolific in this respect than Victoria except upon Brussels.

TABLE XXXI.

Effect of variety upon suckering of trees on four rootstocks.

	VICTORIA.			PRESIDENT.			RIVERS' EARLY PROLIFIC.		
	No. of trees.	No. suckered.	No. of suckers per tree suckering.	No. of trees.	No. suckered.	No. of suckers per tree suckering.	No. of trees.	No. suckered.	No. of suckers per tree suckering.
Broad Leaved Mussel ..	7	3	14	12	11	34	11	5	3
Common Mussel	5	5	26	12	12	45	11	7	20
Common Plum ..	5	4	18	3	2	30	11	11	17
Brussels ..	5	5	55	4	4	41	11	11	18
All Stocks ..	22	17	30	31	29	39	44	34	16
	77% suckering.			94% suckering.			77% suckering.		

An interesting detail worth recording is the fact that none of the Victorias on Brompton raised from shoot or wood cuttings or layers have sent up any suckers. In the previous discussion ample evidence was presented to show that suckering was equally prevalent upon such stocks as St. Julien raised from seed, and that the habit was by no means confined to vegetatively raised stocks as has not infrequently been suggested.

DISCUSSION.

Though the present investigations have suffered several disturbing factors such as the incidence of disease and the discovery of delayed incompatibility, yet they have already afforded sufficient evidence to show that rootstocks influence both the growth and cropping of different plum scions to a striking degree.

Whilst it has so far proved impossible to evolve a logical explanation of these differences along the lines of the relationship between species and varieties and their consequent behaviour, one or two fairly general principles do seem to be emerging. It appears fairly safe to conclude that P. cerasifera rootstocks will in general give the most vigorous trees and that at least some of those representing P. insititia species such as the Common Mussel, Common Plum and some of the St. Julien selections may be expected to produce trees of comparatively moderate vigour.

Vigour and cropping are not necessarily closely associated at least up to the end of fourteen years, for although in the majority of cases the trees with large potential bearing areas are by now bearing heavy crops, in several notable instances varieties upon Pershore and Marianna which are making much more moderate growth are still cropping as heavily as the larger trees.

It seems evident that the success of particular combinations of stock and scion is more important in the case of plums than of apples, but it is difficult to suggest whether this is due to the greater number of species and range of varieties under trial or whether the phenomenon of delayed incompatibility in plums is more widespread than is at present apparent.

The investigation into the possibilities of growing plum varieties upon their own roots has not yet proceeded far enough to draw any final conclusions therefrom. Were it not for the greater ease with which most varieties can be reproduced by budding or grafting, the present evidence suggests that the varieties tested crop as well on their own roots as on a precocious stock. On the other hand in the majority of cases there is evidence that bigger trees are developing more rapidly upon P. cerasifera rootstocks. Once these have come into bearing it is reasonable to suppose that they will bear equivalently heavy crops.

The study of seedling rootstocks has shown great variation to exist amongst the commercial races of St. Julien and Black Damas. These variations manifest themselves subsequently in the plantation by striking differences in vigour and cropping. The differences in trees on the seedling Myrobolan (P. cerasifera) are not very marked in the plantation, though in certain seasons the variable "take" of buds on different clonal selections warrants the establishment of suitable clonal races, especially since they can be readily multiplied from ordinary cuttings.

Rootstock has also been found to affect the time of ripening and the size of fruit of certain varieties, more in some seasons than in others, but it has not been found possible from the nature of the fruit and the method of its harvesting to obtain very detailed records on a large scale.

Though resistance to Silver Leaf and Bacterial Dieback are obviously more a matter of variety than rootstock, it seems more than likely that trees on Common Plum recover more readily from the former than on any of the other rootstocks tested.

The results so far obtained suggest that a detailed study in the nursery of the widest possible range of combinations of rootstock and scion with a view to discovering a number of "incompatibilities" and "partialities" will prove the most profitable way of extending the investigations. Indeed such a scheme is already under way and an intensive study of the possible causes of "incompatibility" has already been initiated.

PRACTICAL APPLICATION OF RESULTS.

There is no longer any doubt that the fruit farmer should be just as inquisitive about the rootstocks upon which his plums are budded as he has become "stock conscious" in ordering his apple trees. If he wishes to obtain large trees suitable, according to variety, for planting at from sixteen to twenty feet apart, he can with safety rely on the Myrobolan rootstock. The East Malling selection—Myrobolan B—has now been widely distributed to the English nursery trade and it appears to serve its purpose admirably.

Probably the Brompton stock—apart from its propagation for peach budding—is not sufficiently widespread to become a practical proposition. However it has several good qualities to recommend it. It is generally compatible with most varieties ; it produces vigorous, well anchored trees which crop creditably and sucker little, but since a standardized Myrobolan also serves these purposes, there seems no reason to multiply the number of rootstocks unduly.

Where the growers are anxious to obtain very early crops of such plums as Victoria, which not infrequently become infected with Silver Leaf in later years, they will do well to consider the record of trees on Common Plum in particular and plant these closely at twelve or fourteen feet apart.

Amongst the other precocious rootstocks, the Yellow Egg (Pershore) is outstanding, and but for the fact that the rootstocks are not usually readily obtainable in quantity, quality and true to variety, and that trees on this stock appear to be rather poorly anchored, there seems to be every reason why it should become the most widely used of all plum stocks until such time as an improved form can be found.

In the very early years the trees of Victoria on Common Mussel showed exceptional promise, which has not been fulfilled in later life. It seems probable that this rootstock may have rather special manurial requirements, since on soils liable to leaf scorch trees on this stock appear to be amongst the first to become affected. The other disadvantage to the stock is its propensity to suckering.

Growers are bound to be attracted by the performance of many of the varieties tested upon the Marianna stock and to ask why this does not receive an unqualified recommendation. There are at the Research Station a number of varieties from eleven to fourteen years old on this rootstock growing perfectly healthily and cropping exceptionally. There is a tradition amongst some nurserymen of wide experience that "trees do not do on Marianna". It is true that, like Common Plum and Brussels, it proves incompatible in the nursery to certain varieties, but unfortunately this fault was not enough to banish the ubiquitous

Brussels. Marianna can be easily raised from cuttings and it is certainly worth a trial, on its recorded performance, with a limited number of varieties. Were the results not so outstanding, reluctance to introduce a new variety of rootstock to commercial notice would have proved the deciding factor. Probably the ideal stock for a precocious dwarf plum tree has yet to be discovered ; none have as yet been under trial sufficiently long at East Malling.

Although at East Malling there are trees of Czar and President surviving on stocks known to be incompatible to them such as Common Plum, Brussels and possibly Marianna, it would be most unwise for the commercial grower to risk such combinations.

With the possible exception of Victoria, trees on the Brussels stock are, by comparison, most mediocre in performance. Unfortunately this stock is probably by far the most widely distributed vegetative stock in Europe because it is so easy to raise. It cannot be recommended for any variety in preference and for most it should be abandoned. It is also hoped that growers will realize the variable performance they are likely to obtain from trees on Seedling St. Julien and Black Damas. Whilst many individual trees are excellent, no uniformity can be relied upon.

ACKNOWLEDGMENTS.

In an investigation involving field experiments of this magnitude carried on over a period of years, it is extremely difficult to give due credit to all those who have been concerned and deserve it. Mr. Amos has been closely associated with the present writer in the execution of the experiments from their inception to the present time and his collaboration has been indispensable. He also took the photographs. The detailed recording of weights and measurements has in recent years been undertaken at one time or another by practically all members of the assistant pomological staff most carefully and patiently. In the early years the late Miss A. D. MacKenzie was especially associated with the recording and in recent years Miss A. B. Beakbane has undertaken the organization of this work. Only those who have shared in taking these records can sufficiently appreciate the arduous task which has been so admirably and willingly undertaken.

Since the formation of the Statistical Section, Mr. Hoblyn has been closely associated with the work and best thanks are due to him and his assistants for summarizing the numerical data and examining the significance of the results. His collaboration with Mr. Amos and other members of staff mentioned in the text in editing the final draft during the writer's absence abroad is very much appreciated.

SUMMARY.

1. The position with regard to varieties of rootstock, their methods of propagation, present use, are summarized.

2. A small investigation of the comparative behaviour of a clonal rootstock raised by different vegetative methods is reported.

3. Data from trees growing on different clonal races of Myrobolan and St. Julien are presented to illustrate the degree of variability resulting.

4. Three field trials comparing the growth and cropping of certain representative and local plums on their own roots and budded upon foreign rootstocks are described. At present trees on Myrobolan are growing more vigorously than the same varieties on their own roots—Victoria is an exception and propagates readily from layers.

The trees have cropped as well on their own roots as on Common Mussel or Common Plum stocks.

5. The measurements of vigour and weight of crop from three successional plantings embracing fourteen varieties and eight principal rootstocks—from eleven to fourteen years old—are presented and discussed.

Considerable differences in vigour as expressed in cross section of stem and total weight of tree are demonstrated and proved significant. Similar comparisons are given in relation to total crop and earliness of coming into bearing.

6. Size of tree in relation to distance of planting and crop per acre is discussed.

7. Nearly all varieties on Myrobolan are the most vigorous. Trees on Common Plum, Brussels and Common Mussel are usually partially dwarfed.

In relation to size of tree, the crops from Yellow Egg stock and Marianna are frequently outstanding.

8. Some influences of rootstock on time of ripening and size of fruit are illustrated.

9. The value of certain local rootstocks is tested in comparison with better known stocks.

10. The relationship of variety and rootstock to death from Silver Leaf, Bacterial Dieback and Delayed Incompatibility is reviewed.

11. The development of sucker growths from the roots is shown to be chiefly dependent upon the rootstock but also influenced by scion variety.

12. The general trend of the results is discussed and practical suggestions made to the fruit grower.

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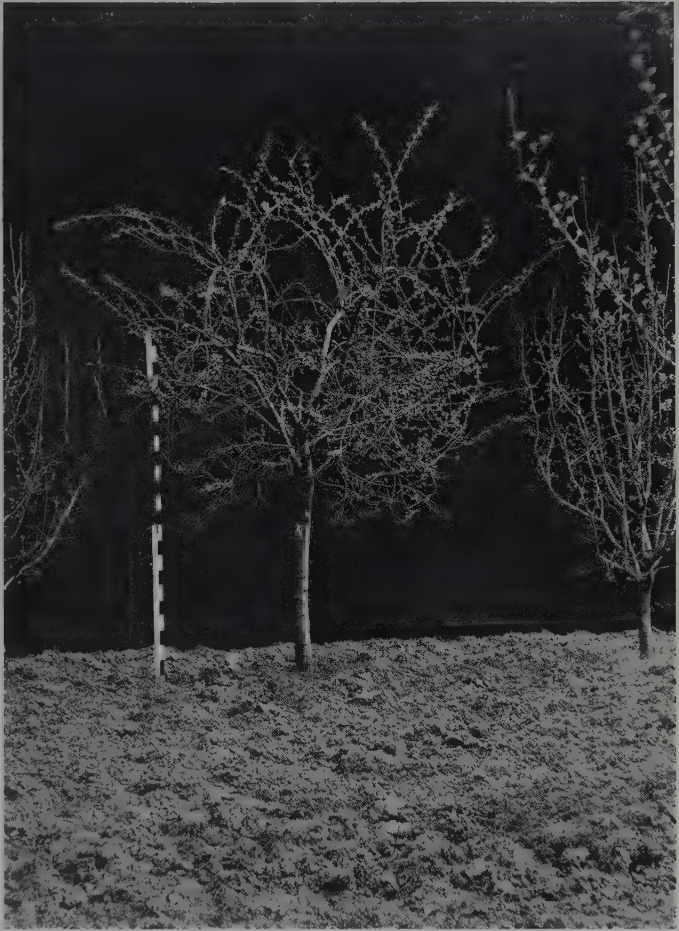

FIG. 1. Victoria on Common Plum, thirteen years old.

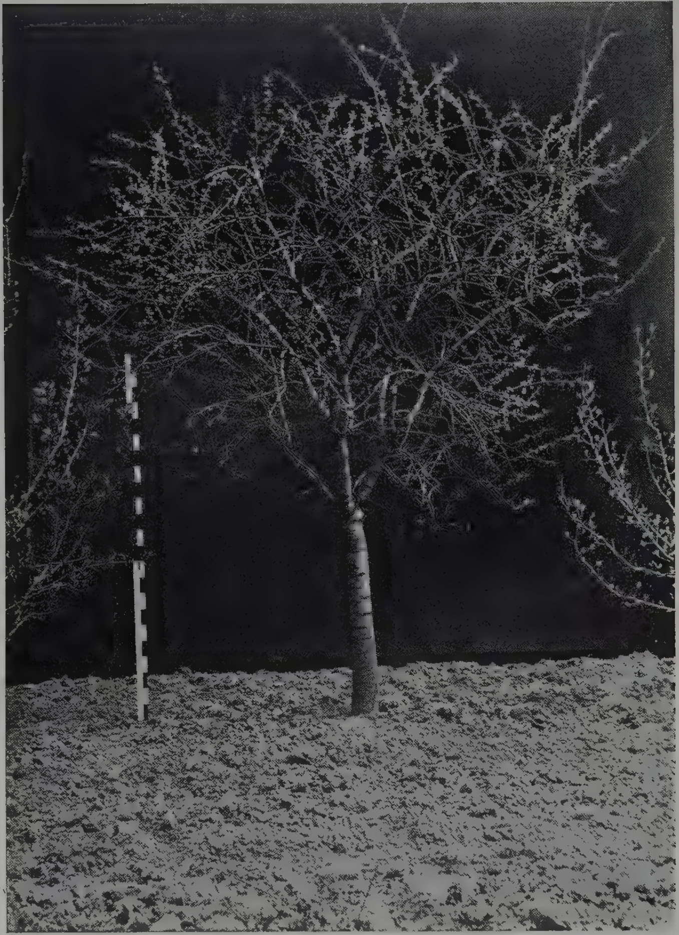

FIG. 2. Victoria on Myrobolan, thirteen years old.

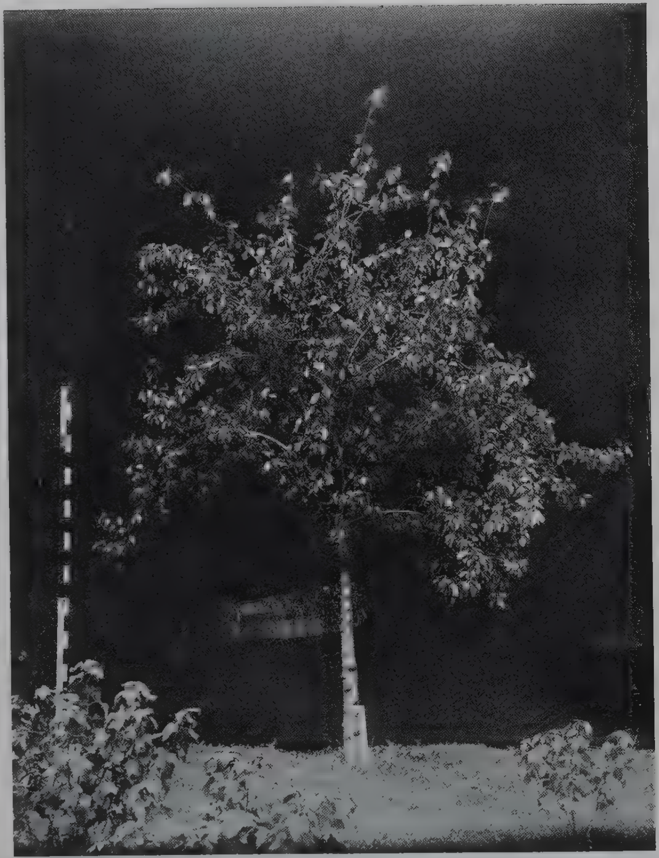

Fig. 3. Pershore on Common Plum, ten years old.

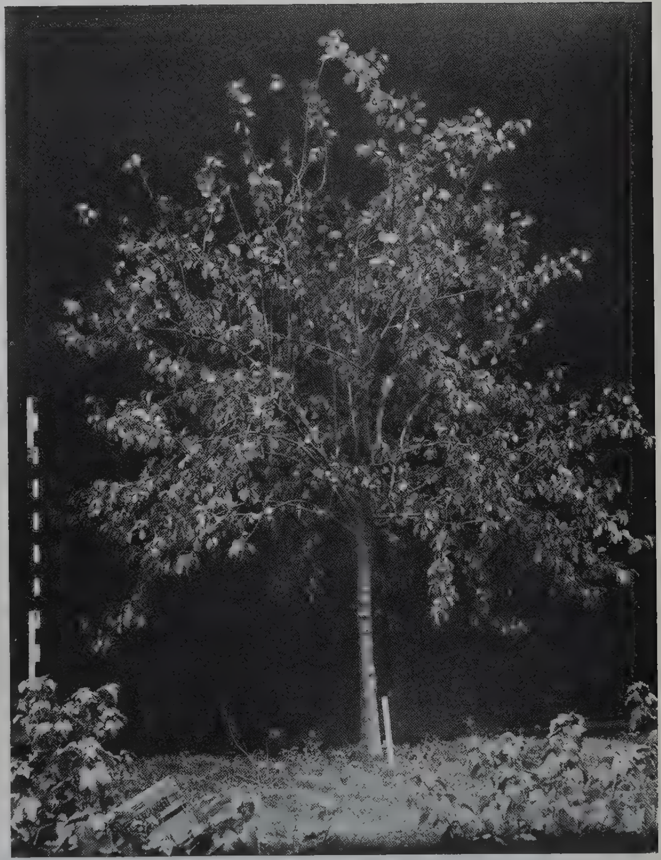

Fig. 4. Pershore on Own Roots, ten years old.

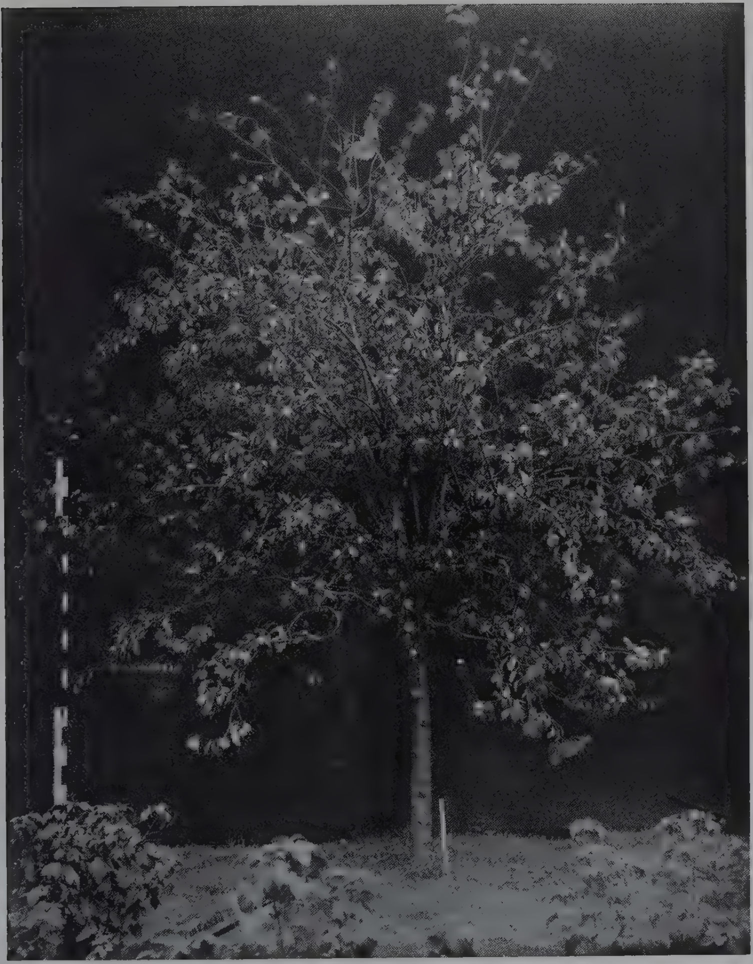

FIG. 5. Pershore on Myrobolan B, ten years old.

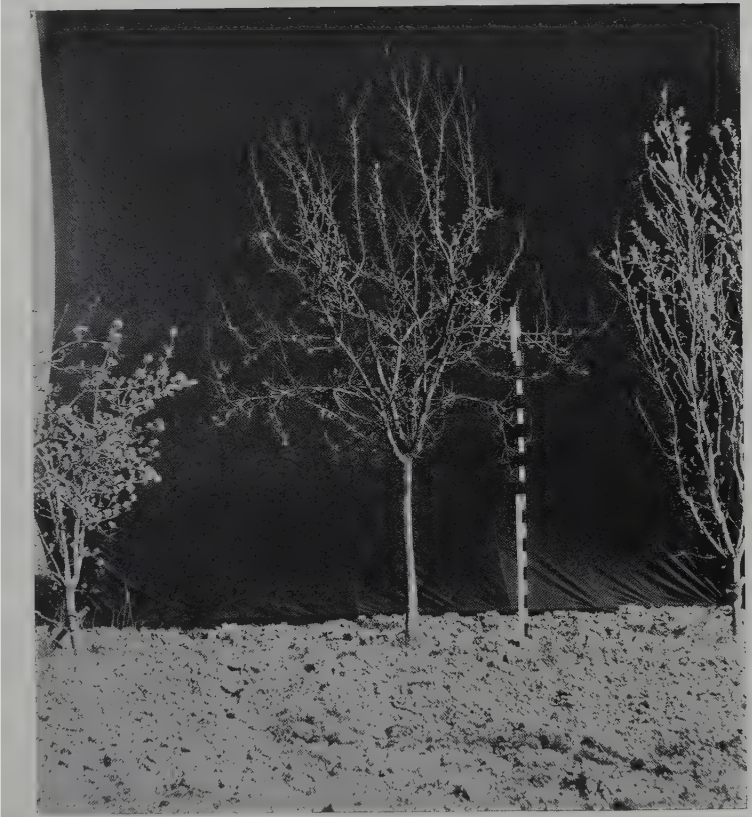

FIG. 6. Czar on Brussels, thirteen years old.

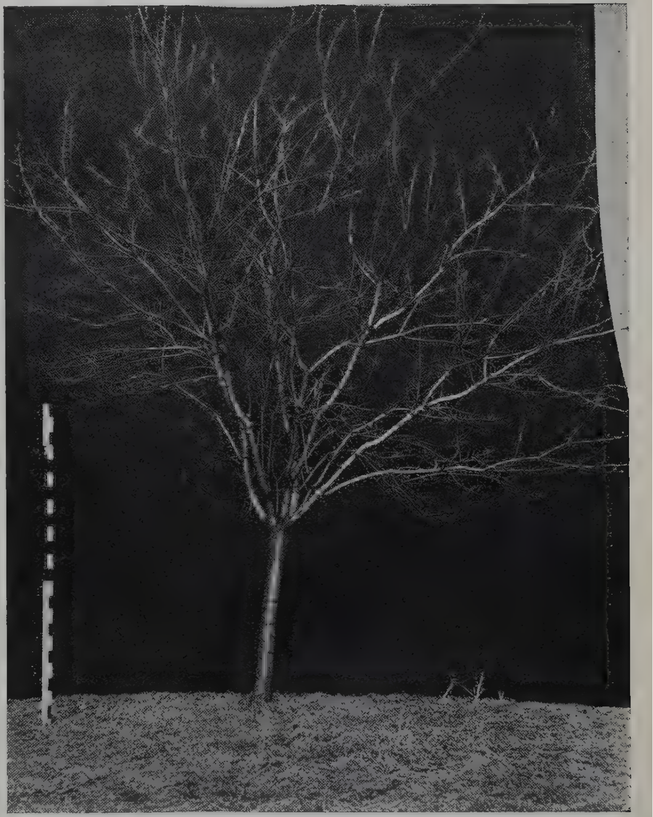

FIG. 7. Czar on Myrobolan, thirteen years old.

STUDIES ON THE RESISTANCE AND IMMUNITY OF APPLES TO THE WOOLLY APHIS, *ERIOSOMA LANIGERUM* (Hausm.)

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INTRODUCTION.

The Woolly Aphis, *Eriosoma lanigerum* (Hausm.), or American Blight, has been a serious pest on apple trees for many years. In certain countries, notably Australia, New Zealand and South Africa, its prevalence has necessitated the use of an immune root system and main stem upon which varieties susceptible to the pest are over-worked either by budding or grafting. The known immunity of Northern Spy has brought about its general adoption for this purpose, although as a rootstock it has often proved undesirable in other respects. In this country, however, the attacks of Woolly Aphis are not generally severe enough to justify the replacement of the valuable series of "Paradise" apple rootstocks, now in common use, by varieties inferior to them in every respect save immunity.

The experiments described in this report were initiated jointly by Mr. R. G. Hatton, Director of the East Malling Research Station, and Mr. M. B. Crane, of the John Innes Horticultural Institution, Merton, in 1922. The various problems, to which the injurious attack of the Woolly Aphis on apples gives rise, were considered, and one of the original objects of the experiments was to obtain a series of apple rootstocks in which immunity to attack was combined with other desirable characters. But from the inception of the experiments the entomological and genetical aspects have been studied in addition to the more directly economic problems.

Breeding experiments were begun at Merton by Crane, who crossed some of the "Paradise" rootstocks with the immune variety, Northern Spy. It was realized at this time that no one rootstock, though possessing immunity, was likely to be of general use or equal value for all pomological requirements, and later Hatton (6) showed that in this country Northern Spy does not make so satisfactory a rootstock as the varieties of "Paradise" rootstock in common use. The latter, on the other hand, are all more or less susceptible to the Woolly Aphis.

In the early years the entomological part of the investigation was undertaken by Staniland (13, 14). His collaboration, however, was unavoidably interrupted by his appointment to the Long Ashton Research Station. Staniland was followed for a short period by Le Pelley (9) who published a paper in which some preliminary results of the experiments were described. From the beginning of the work up to 1927 the experiments were conducted on a comparatively small scale, but from this time they were very considerably developed. At Merton Mr. W. J. C. Lawrence for some years assisted in the breeding work, while at East Malling, Massee and Greenslade have carried out the entomological investigations, introduced new methods of technique, and made a detailed study of the life history of the Woolly Aphis. In collaboration with Roach (4, 12) they have also begun physiological investigations, with a view to elucidating the underlying causes of immunity. Tydeman (15, 16) has done considerable breeding work at East Malling, and has also begun a detailed study of the root-systems and other characters of some of the immune seedlings.

In the report which follows, Massee and Greenslade are responsible for the entomological, and Crane for the genetical account, whilst Tydeman is responsible for the description of the characters and comparative analysis of the immune seedlings. There has been, however, close collaboration throughout the work, and any outcome is essentially the result of collective effort.

OUTLINE OF LIFE CYCLE OF THE APHIS.

The Woolly Aphis, *Eriosoma lanigerum* (Hausm.), was originally a North American insect living on wild apple, mountain ash, hawthorn and American elm (*Ulmus americana*). With the rise of fruit-growing it became a serious pest of cultivated apples and in just over a hundred years it has been spread with nursery material to almost every apple growing country in the world. In the course of this dissemination its life cycle has been considerably altered. An outline of the life cycle may be given here. In the eastern side of the United States and Canada there is a winter egg stage on *Ulmus americana*. The egg hatches in the spring to produce a stem mother or fundatrix, which attacks an expanding bud, causing it to form a "rosette" of leaves instead of the normal shoot. Inside the rosette the fundatrix produces a generation of wingless females. These in turn give rise to a generation of winged females (spring migrants) which fly to the apple or other summer host and produce another wingless generation. Several generations of these follow one another through the summer, and in autumn two forms occur in the same brood: (a) wingless females similar to the summer broods, which remain on the apple all the winter, and (b) winged females (fall migrants) which return to the elm and deposit the sexual forms by which the egg is laid. Thus there are two distinct cycles, one that remains on apple all the year round and one that alternates between apple and elm.

In other parts of the world, including America west of the Rockies, the absence of American elm renders the complete cycle impossible and only the apple cycle remains. The autumn winged forms are still produced and still give rise to the sexual forms but often the egg is not laid ; if it is laid it does not hatch, or in the rare cases of hatching the fundatrix cannot establish itself even on American elm.

Woolly Aphis, in all its stages of development, feeds by means of its piercing and sucking mouth-parts on the shoots, stems and, in some cases, roots of the tree. The leaves are not damaged and the fruit only exceptionally, when a colony becomes established in the core. Their feeding stimulates the growth of a gall-like area which generally splits and provides a point of entry for fungous diseases. Damage resulting in economic loss may occur in several ways. Seedlings and the shoots of young trees may be stunted or killed by the direct effect of the feeding of the aphis. This is not usually serious on established trees except with certain very susceptible varieties. Indirect damage may be caused by the entry of canker-producing fungi at the broken galls. In this country the apple canker fungus, *Nectria galligena*, enters in this way, and on the Pacific coast of America *Gloeosporium perennans*, which produces the so-called perennial canker, is particularly serious where Woolly Aphis is bad. Loss may also be caused when nursery material is rendered unsaleable by reason of galling. Damage to the roots, where it occurs seriously, reduces the vigour of young trees, but on older trees is not so serious ; at any rate there are records of trees continuing to crop and showing no loss of vigour though heavily infested on the roots. Root infestation is, however, undoubtedly serious as providing a "reservoir" of insects which cannot be controlled, and which may re-infect the tops of the trees.

It has been observed in practice that certain varieties of apple are not much troubled by Woolly Aphis while others are nearly always heavily infested. Certain varieties, notably Northern Spy and Winter Majetin, appeared to be completely immune to its attack. Le Pelley (9) has shown that the aphides will feed for a time on Northern Spy but they do not reproduce and do not stimulate the formation of galls. For practical purposes, therefore, this variety may be regarded as immune, though there are all grades of resistance from this to complete susceptibility.

The use of "immune" varieties as a means of controlling Woolly Aphis was naturally suggested, and although it is not always practicable to use them as scion varieties, they have considerable value as rootstocks in places where the roots are infested. By keeping the roots free of the aphis, control measures may be applied to the upper parts of the tree. The variety Northern Spy has been mainly used for this purpose, and in Australia and South Africa, where root damage is serious, most orchards are on resistant stocks. They are particularly valuable where the parasite, *Aphelinus mali*, is used, as the control exercised by the parasite is not then vitiated by the existence of a supply of aphis on the roots.

In many cases where resistant rootstocks are desirable, there are definite objections to the use of the varieties at present available and this led to the investigations now in progress at the John Innes Horticultural Institution and East Malling Research Station.

MATERIAL USED IN THE EXPERIMENTS.

The following rootstocks and varieties of apples have so far been used in the experiments:

"Immune"

Northern Spy
Winter Majetin
Irish Peach
Ben Davis
Reinette Zuccamaglio
Transparente de Croncels
Jonathan
Duchess of Oldenburg
Carrington Red
No. 779. } Seedlings derived from
,, 789. } Malling No. II ×
,, 793. } Northern Spy

Susceptible

Malling No. I
,, ,, II
,, ,, IV
,, ,, VII
,, ,, VIII
,, ,, IX
,, ,, XII
,, ,, XIII
,, ,, XV
Bristol O.F.5*
Lane's Prince Albert
Stirling Castle
Allsopp's Early
Kirk's
Cox's Orange Pippin

In this paper the word "immune" refers to varieties which are not attacked under natural conditions, but some of which may be slightly attacked when tested under the rigorous conditions of the greenhouse. Le Pelley (9) showed that woolly aphis could feed even on the "immune" variety Northern Spy but that no galling occurred and the aphides did not breed. He showed that the variety Winter Majetin was similarly resistant as are the seedlings 779, 789, 793. The varieties Irish Peach, Ben Davis, Reinette Zuccamaglio, Transparente de Croncels and Duchess of Oldenburg could all be infected slightly in the greenhouse but for practical purposes may be described as highly resistant.

It may be recalled that apples are of two kinds, those with 34 and those with 51 chromosomes, the so-called diploids and triploids respectively. Some of the varieties and rootstocks we have used as parents still await cytological examination, but from their fertility, vigour and behaviour in breeding there is little doubt that at least all those which have been used extensively in breeding are diploids.

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* Now known as G.8.

During the earlier years, breeding work was largely concentrated on intercrossing Northern Spy with a number of the Malling series of "Paradise" apple rootstocks. Hatton (5) has been able to divide these "Paradise" rootstocks into four classes with respect to their influence upon the scion, as follows: (a) *Dwarfing*, of which both Nos. VIII (French Paradise) and IX (Jaune de Metz) were used in these experiments; (b) *Semi-dwarfing*, represented by No. II (Doucin), No. IV (Holstein Doucin) and No. VII (name unknown); (c) *Vigorous*, represented by No. I (Broad-leaved English), Nos. XIII and XV (un-named seedlings of German origin); and (d) *Very vigorous*, represented by Nos. XII and Bristol O.F.5. In the light of more recent researches Hatton (7) has found a slight modification of the above grouping necessary.

While, in general, it was desired to use as wide a range of these rootstocks as possible in order to explore their potentialities as parents, certain of them were used with a specific object in view. Thus No. IV, in its earlier years, imparted to the scion variety an almost unique combination of vigour and precocity, and it was thought well worth while to attempt to combine these desirable characters with immunity; No. XV was used because, although not actually immune, it is one of the least susceptible of the Malling series. All these "Paradise" rootstocks were susceptible in greater or lesser degree to attacks of Woolly Aphis under East Malling conditions, while Northern Spy has always proved immune.

More recently other reputed immune varieties were introduced into the experiments, first because the undesirable characters of Northern Spy, particularly susceptibility to mildew, were evident to a considerable degree among its offspring, and secondly with a view to obtaining scion varieties of apples which would combine size, colour, flavour and other desirable characters with immunity to the Woolly Aphis. It was, however, some years before material was available for this purpose. In 1932 the varieties Irish Peach, Transparente de Croncels and Reinette Zuccamaglio were introduced, and in subsequent years Winter Majetin, Ben Davis, Jonathan and Duchess of Oldenburg. The susceptible varieties, Cox's Orange Pippin and Stirling Castle, were also used. In the autumn of 1932 the varieties Allsopp's Early, Kirk's and Carrington Red were imported from Carlingford, New South Wales, where they were reputed to be resistant. Under test at East Malling only one of these, Carrington Red, was found to be immune. All, however, were used in crosses in 1934.

After the fruits resulting from cross-fertilization are fully ripe, the seeds are extracted and sown in boxes. They usually germinate in the following

February or March and the seedlings are subsequently potted into three-inch pots. In May, when the plants are about four inches high, they are passed on for the entomological tests. At the beginning of the experiments the seedlings were infested with the Woolly Aphis in the field, but in later years the infestations and immunity determinations have all been made at East Malling in a greenhouse specially designed for entomological investigations. The provision of this house has considerably expedited the work, afforded greater control and enabled larger quantities of seedlings to be dealt with.

ENTOMOLOGICAL TECHNIQUE.

Since the inception of the work of testing the resistance to Woolly Aphis of apple rootstocks and seedlings in February 1921, modifications in methods of technique have been made from time to time. Routine methods have now been worked out, the one limiting factor being the amount of greenhouse space available for housing the seedlings while the tests are being made.

The initial tests were made by Staniland (13) at the Chelsea Physic Garden. In this experiment the rootstocks were grown in large pots and were placed four abreast out in the open. The inoculation of aphides was made in successive blocks. Later on in the season details were obtained of the degree of infestation of the various rootstocks. All the aphides used for making these direct inoculations were obtained from a wild crab apple tree growing in a garden in North London. The aphides were transferred to the rootstocks by means of a brush. First the aphides were carefully brushed off the infested shoots into a Petri dish and were then transferred to the stocks. The root inoculations were made by the same method.

During the same year Staniland also carried out some experiments using Seedling Free Apple Stocks at East Malling, but the methods employed for testing these seedlings were very different from those used in the investigation at the Chelsea Physic Garden. The seedlings were growing in the nursery rows in the usual manner, and selected batches of these seedlings were inoculated *in situ*. The seedlings were enclosed by means of corrugated iron, and were covered with light sacking to check the spread of the aphides to other parts of the nursery. This method of testing seedlings was soon superseded on account of the risk of general infection of the apple stocks in the nursery, and owing to the technical difficulty of inoculating the seedlings.

A third method of testing seedlings was also tried. In this case a number of seedlings were transplanted in a garden at West Malling, Kent, which contained a number of apple trees known to be heavily infested with Woolly Aphis every year. The seedlings were left to become naturally infested. The following season all the seedlings were noted to be attacked by Woolly Aphis.

In 1924 Le Pelley (9) continued the entomological aspect of the testing of seedlings and still further modifications were made in the methods of technique employed. At first it was planned that the experiments should be conducted in the open as previously, and that a few plants should be potted up and kept in a greenhouse where conditions would be more favourable for the breeding of the aphides. As time went on it was found desirable to carry out all the tests under glasshouse and insectary conditions. This decision was arrived at for various reasons. In the first place it proved to be very difficult to establish colonies of aphides on some of the seedlings under natural conditions. Many of the aphides were destroyed by predaceous insects, such as Ladybird Beetles, while heavy rain storms and windy weather also tended to prevent colonies from becoming established.

In addition it was noted that some of the seedlings which appeared to be immune when tested in the field were actually shown to be susceptible when more stringent tests were made under glass.

The methods for making the direct inoculations were again modified in 1926. It had been the practice previously to use aphides obtained from one source, and to breed colonies from them on a susceptible apple such as Kentish Codlin and Lane's Prince Albert. Infested branches were cut off the tree and the aphides required for the inoculations were removed singly under a binocular microscope, by teasing them with a needle, until they withdrew their stylets. The method proved to be far too tedious when large numbers of inoculations had to be made at frequent intervals.

Another method, and one which proved to be quite satisfactory, was next adopted. Short lengths of shoots having established colonies of aphides were cut and placed in pill boxes. After three or four days some of the aphides would leave the shoots and wander about in the boxes. These were removed by means of a camel hair brush and were used for making the inoculations.

For making root inoculations the following method of technique has always been used and it has proved to be entirely satisfactory. In pot experiments the root is exposed by digging a small hole. The root is then inoculated with aphides by means of a camel hair brush, and covered with soil to a depth of half an inch. Above this an inverted watchglass is placed, and the rest of the hole is filled in with soil. When it is desired to examine the root, the earth is removed until the watchglass is exposed, then the exact position of the initial inoculation can be readily ascertained, and by removing the remaining half inch of soil the root can be exposed for examination.

Now all the seedlings tested up to the end of 1929 were in their third or fourth year ; thus many of them were growing vigorously and required large pots, and only a very few seedlings could be tested each year in the limited greenhouse space available. This consideration was overcome in 1930 when it was decided to carry out the tests on young seedlings in their first year. Such seedlings were contained in three-inch pots or even smaller ones.

In order to ascertain whether the very young seedlings were just as suitable for applying the tests as the older ones a long series of tests was necessary ; these showed that the small seedlings gave results just as reliable as those obtained by using the older plants. By using the small seedlings the investigations were greatly expedited. In fact some thousand seedlings could be tested every year, whereas in the past only a tenth of this number could be tested conveniently.

Before the young seedlings were inoculated, steps were taken for the first time in 1929 to eradicate any other insects and mites present on the seedlings, especially upon those seedlings which were being tested for their second season (10). All the seedlings received an application of tar-distillate in the winter and this was followed by two applications of lime-sulphur in the spring. Thus apple aphides, Fruit Tree Red Spiders and Mildew which frequently infest the seedlings were wiped out or greatly reduced.

As stated at the beginning, the testing of apple seedlings for their resistance to Woolly Aphis has now become a matter of routine, and it may be of interest to outline briefly the actual methods used at the present time.

As soon as they are big enough to be potted up (Fig. 1) the seedlings are placed on slate benches covered with ashes in the greenhouse. They are kept in as healthy a condition as possible, and the inoculations are begun in May or as soon as sufficient Woolly Aphis is available.

For this purpose aphides are bred on susceptible varieties grown in pots, and to ensure sufficient material for the early infections colonies of aphides are bred during the winter on these plants in the greenhouse. In addition, a further supply of Woolly Aphides is obtained from infested trees in a neighbouring orchard. The inoculations are made by placing cut shoots heavily infested with aphides amongst the seedlings, and by making direct inoculations of the aphides by means of a camel hair brush. For this purpose, it has been ascertained that it does not matter whether the stylets of the aphides are damaged or not when they are removed from the twigs, since the aphis is still able to reproduce even if it is unable to feed owing to its mouth-parts being damaged. Once colonies of aphides have become established on a seedling and it is deemed to be susceptible, then the aphides are removed and other seedlings are inoculated with them.

As already mentioned the inoculations are begun in May, or as soon as aphis material is available and the seedlings are inoculated weekly until the end of October. Once colonies of aphides are established on any seedling it is considered to be susceptible to attack and it is discarded. Those not attacked continue to be inoculated until the end of the season when a final survey is made, and all those still unattacked are retained for a second season's testing.

It is considered that if a seedling remains uninfested after two seasons' tests under glasshouse conditions, it can safely be described as immune. Some seedlings which were tested in the earlier years and were found to be immune have been tested each year since, along with the immune variety, Northern Spy, and their resistance to attack has been manifest over a period of eleven years, in spite of the fact that in the month of August each year there are so many aphides present in the glasshouse that all plants, whatever they may be, are infested with aphides which are endeavouring to find suitable places for forming fresh colonies.

Some years ago an attempt was made to classify the seedlings into groups according to the degree of resistance. The grouping was as follows: Group 1, seedlings immune. Group 2, very slight infections, not permanent. Group 3, small colonies of aphis formed and small galls developed. Group 4, whole seedlings attacked, infestations severe but not until late in the season. Group 5, whole seedlings attacked, infestations severe as early as August. Group 6, infestations very severe, the seedlings being killed by the severity of the attack (Fig. 2). This method of grouping the seedlings was used until 1932, but from that year onwards they were divided simply into two groups, namely immune and susceptible, the former practice being dropped because of the difficulty of being able to place some of the seedlings into their correct groups.

Once the seedlings have been classified as being immune by the Entomologists they were handed over to the Pomologists who continue to study the seedlings from the Pomological viewpoint.

THE TESTING OF IMMUNE SEEDLINGS ABROAD.

A number of immune seedlings, viz. Merton (Numbers 778, 779, 789 and 793) have been sent to various Institutions abroad, with a view to determining their behaviour under different climatic conditions, at present purely from the entomological and genetical aspects, in other parts of the world.

Clonal material of a limited number of seedlings has been despatched to the following countries: India, Canada, New Zealand, South Africa, Argentine, Morocco, Queensland and Russia. In each case the seedlings have been sent to Institutions where interested persons were available to supervise the testing of the stocks. Some time must however necessarily elapse before the behaviour of the stocks in other countries is reported upon.

CAUSES OF RESISTANCE TO WOOLLY APHIS.

Work on one aspect of the actual causes of resistance to Woolly Aphis was begun by Staniland who studied the feeding of the insects in relation to the structure of the stem. In his paper published in 1924 (14) he showed that, although there may be a relationship between the amount of sclerenchyma in the stem and the degree of resistance, "complete immunity" could not be explained in this way. That aphides will actually feed on Northern Spy, yet cause no galling, and do not appear to reproduce, also suggests that resistance cannot be explained entirely on mechanical grounds.

Roach and Massee (12) tested the possibility that there existed some chemical substance in an "immune" variety which was toxic to the insect, or that some substance necessary for its development was missing from such a variety, by preparing from the living tree a dead medium to be used as food for the aphis, and by this means eliminated anything dependent on the living protoplasm of the cell.

The preliminary report on this work was published in 1931 (12) and a description was given of methods of feeding aphides on artificially prepared food media. Media were made from Northern Spy or from Allington Pippin, as examples of highly resistant and highly susceptible varieties respectively. Of the various methods tried of preparing these media the most satisfactory was to make a boiling water extract from the finely shredded bark. This extract was supplied to the aphides in various ways and the relative length of life of the adults and relative number of young produced were observed. No difference in length of life of the adult placed on the five kinds of media was detected, but the rate of reproduction was slightly higher on the "susceptible" media than on the "resistant" ones.

Hence the great difference in food value between the living varieties was reflected to a small extent in that of the dead culture media prepared from them. This fact seemed to justify an attack on the problem along chemical lines. Accordingly attempts were made to separate the substance carrying immunity or susceptibility from the other constituents of the bark by means of selective organic solvents (4). Successive extractions with alcohol, ether and water removed relatively small quantities of the substance, but most of it remained in the residue. These results suggest that compounds of the hemi-cellulose or pectin type are worth examination. The work is still in progress.

THE HEREDITARY BEHAVIOUR OF IMMUNITY.

The following can only be regarded as a preliminary account of the genetical aspects of the investigations. The prevalence of self-incompatibility and the complex heterozygous constitution of apples prevents a direct approach to genetical studies, and the time which elapses from one generation to another makes breeding investigations prolonged. The work of classification and determination of susceptibility or immunity in the numerous seedlings investigated also involves considerable labour and time. Nevertheless, although from a genetic point of view the available results are limited, the hereditary behaviour of immunity of apples to the attack of Woolly Aphis presents several unusual features, and since so little is known regarding the inheritance of immunity or resistance to insect parasites of any kind, it was thought that a report at the present stage of the experiments would be of value.

The results of the breeding and entomological investigations are detailed in the tables which follow. In Tables I and Ia the seedlings are classified in

Table I.

Susceptible × Immune.

Parents.	Where raised.	Year raised.	No. of Seedlings infested.	Grouped in order of susceptibility.					
				1	2	3	4	5	6
Malling No. IX × Northern Spy	M	1924	22	0	1	0	4	12	5
,, ,, ..	M	1929	12	0	0	0	0	7	5
,, ,, ..	M	1930	1	0	0	0	0	1	0
,, ,, ..	M	1931	6	0	0	0	0	2	4
			41	0	1	0	4	22	14
Malling No. II × Northern Spy ..	M	1930	134	44	18	5	40	12	15
,, ,, ..	M	1931	71	26	0	2	7	22	14
			205	70	18	7	47	34	29
Malling No. I × Northern Spy ..	M	1930	63	21	9	1	17	7	8
,, ,, ..	M	1931	123	57	1	5	5	28	27
			186	78	10	6	22	35	35

Table Ia.

Immune × Susceptible.

Parents.	Where raised.	Year raised.	No. of Seedlings infested.	Grouped in order of susceptibility.					
				1	2	3	4	5	6
Northern Spy × Malling No. I ..	M	1929	76	2	4	3	22	31	14
,, ,, ..	M	1930	7	3	0	0	2	1	1
.. .. ..	M	1931	79	33	5	0	10	12	19
.. ,, ..	EM	1931	54	9	19	0	14	7	5
			216	47	28	3	48	51	39
Northern Spy × Malling No. II ..	M	1930	21	5	5	1	0	7	3
,, ,, ..	M	1931	38	22	2	0	7	1	6
,, ,, ..	EM	1931	119	46	16	1	5	46	5
			178	73	23	2	12	54	14
Northern Spy × Malling No. VII	M	1929	8	1	1	0	0	3	3
Northern Spy × Malling No. XII	EM	1931	104	34	21	1	14	26	8

ascending order into six groups according to their degree of immunity or susceptibility. Thus in Group 1 the seedlings are immune, in Group 6 they are so highly susceptible that the seedlings are killed by the severity of the attack. Between these extremes, different degrees of susceptibility occur.

In Tables II to VI the seedlings are classified into immune and susceptibles only, those which proved immune to attack being in the immune class, while those which are susceptible in any degree fall into the susceptible class. In these tables further details, such as the number of flowers pollinated and the number of fruits and seeds obtained, are also given. They show that in some matings, as for example Malling No. IX × Northern Spy, Northern Spy × Seedling 789, and in all self-pollinations, a high degree of incompatibility occurs. The families marked M were raised at Merton and those marked EM at East Malling.

The results obtained from crosses between susceptible forms are given in Table II. The numbers of seedlings infested with Woolly Aphis, in individual families are small but they give a total of ninety-six seedlings, all of which proved to be susceptible.

TABLE II.

Susceptible × Susceptible.

Parents.	Where raised.	Year raised.	Flowers pollinated.	Fruits set.	Seeds obtained.	Seeds germinated.	Seedlings infested.	Seedlings immune.	Seedlings susceptible.
Malling No. XV × No. IX	EM	1929	51	30	166	135	19	0	19
Malling No. IX × No. XV	EM	1929	51	19	113	67	19	0	19
Stirling Castle × Allsopp's Early ..	EM	1934	97	4	26	20	20	0	20
Stirling Castle × Kirk's	EM	1934	117	10	59	39	38	0	38

In Table III the results are given of families raised from crossing immune varieties with susceptible varieties, and the results obtained from crossing susceptible with immune varieties are given in Table IV. These tables consist largely of families raised from reciprocal crosses between the immune variety, Northern Spy, and a number of susceptible rootstocks. It will be seen from these tables that the results vary considerably. Malling No. IX × Northern Spy, and the reciprocal cross, gave no immunes, out of a total of 53 plants. The 27 seedlings raised from the immune variety Transparente de Croncels × No. IX were also all susceptible. The following families also gave all susceptible offspring: Lane's Prince Albert and Malling No. XIII × Northern Spy, Ben Davis × Malling No. II, Stirling Castle and Malling No. VIII × Carrington Red, Northern Spy × Malling No. XV, and Malling No. XII × Northern Spy. Most of these families were small, but in the family raised in

1934 from Malling No. VIII crossed with the immune variety, Carrington Red, the number of individuals (132) is moderately large. Northern Spy × Malling No. IV entirely failed. In all the other families in Tables III and IV immunes occur, but the proportions of immune and susceptible differ considerably. Thus, taking the extremes, Northern Spy × No. I gave 21 per cent. immune out of a total of 333 plants, whereas Bristol O.F.5 × Northern Spy gave 46 per cent. immune in a family of 150 plants. Northern Spy × No. II gave 34 per cent. immune, whilst the reciprocal cross gave 25 per cent. immune.

TABLE III.

Immune × Susceptible.

Parents.	Where raised.	Year raised.	Flowers pollinated.	Fruits set.	Seeds obtained.	Seeds germinated.	Seedlings infested.	Seedlings immune.	Seedlings susceptible.
Northern Spy × Malling No. II ..	M	1930	115	4	26	21	21	5	16
,, ,, ..	EM	1930	59	4	22	21	21	0	21
,, ,, ..	M	1931	32	5	42	38	38	22	16
,, ,, ..	EM	1931	236	21	144	120	119	46	73
,, ,, ..	EM	1932	269	12	95	70	70	19	51
			711	46	329	270	269	92	177
Northern Spy × Malling No. I ..	M	1929	117	8	84	82	77	2	75
,, ,, ..	M	1930	18	1	9	7	7	3	4
,, ,, ..	EM	1930	31	6	45	37	37	0	37
,, ,, ..	M	1931	158	11	83	79	79	33	46
,, ,, ..	EM	1931	128	9	75	57	54	9	45
,, ,, ..	EM	1932	101	12	100	79	79	23	56
			553	47	396	341	333	70	263
Northern Spy × Malling No. IX ..	M	1924	129	10	5	5	5	0	5
,, ,, ..	M	1926	104	1	7	6	6	0	6
			233	11	12	11	11	0	11
Northern Spy × Malling No. XII ..	EM	1930	63	4	30	28	20	0	20
,, ,, ..	EM	1931	96	14	146	122	104	34	70
			159	18	176	150	124	34	90
Northern Spy × Malling No. VII ..	M	1929	29	1	9	8	8	1	7
Northern Spy × Malling No. XV ..	EM	1930	16	10	82	71	71	0	71
Northern Spy × Malling No. VIII ..	EM	1932	155	6	58	50	50	2	48
Northern Spy × Malling No. IV ..	EM	1932	174	0	—	—	—	—	—
Northern Spy × Stirling Castle ..	EM	1934	103	6	75	53	53	4	49
Northern Spy × Cox's Orange ..	EM	1934	163	3	27	21	20	3	17
Ben Davis × Malling No. II ..	EM	1934	49	4	22	9	7	0	7
Transparente de Croncels × Malling No. IX	EM	1934	102	5	42	27	27	0	27

The results, however, are complicated by the behaviour of the seedlings raised at East Malling in 1930. As shown in the Tables, all the offspring from crosses with Northern Spy raised at Malling in that year are exceptional in giving all susceptible offspring. Thus EM 1930, No. II × Northern Spy (76 plants) and the reciprocal (21 plants) were all susceptible. If these exceptional EM 1930 results are extracted from the tables, the differences in the reciprocal families are not so considerable. They are, No. II × Northern Spy, 31 per cent. immune and Northern Spy × No. II, 37 per cent. immune. Families of the same parentage raised at Merton in 1930 were tested for immunity at East Malling under similar conditions ; since these gave immunes, a difference

TABLE IV.

Susceptible × Immune.

Parents.	Where raised.	Year raised.	Flowers pollinated.	Fruits set.	Seeds obtained.	Seeds germinated.	Seedlings infested.	Seedlings immune.	Seedlings susceptible.
Malling No. II × Northern Spy ..	M	1920	42	12	60	38	36	5	31
,, ,, ..	M	1930	235	26	172	137	134	44	90
,, ,, ..	EM	1930	144	24	92	76	76	0	76
,, ,, ..	M	1931	79	16	112	72	71	26	45
,, ,, ..	EM	1932	151	25	102	82	81	26	55
			651	103	538	405	398	101	297
Malling No. I × Northern Spy ..	M	1930	21	15	110	65	63	21	42
,, ,, ..	EM	1930	27	3	12	5	5	0	5
,, ,, ..	M	1931	84	18	125	123	123	57	66
			132	36	247	193	191	78	113
Malling No. IX × Northern Spy ..	M	1929	647	17	43	38	35	0	35
,, ,, ..	M	1930	156	1	2	1	1	0	1
,, ,, ..	M	1931	91	2	6	6	6	0	6
			894	20	51	45	42	0	42
Malling No. XV × Northern Spy ..	EM	1930	6	4	34	28	28	0	28
,, ,, ..	EM	1934	73	21	170	68	68	11	57
			79	25	204	96	96	11	85
Malling No. XII × Northern Spy ..	EM	1930	53	10	43	34	22	0	22
Malling No. XIII × Northern Spy ..	EM	1930	30	3	12	9	9	0	9
Malling No. VIII × Carrington Red	EM	1934	145	45	305	272	132	0	132
Lane's Prince Albert × Northern Spy	M	1924	50	4	11	8	7	0	7
Bristol O. F. 5 × Northern Spy ..	EM	1932	109	63	445	408	150	70	80
Stirling Castle × Carrington Red ..	EM	1934	157	4	35	17	16	0	16

in the virulence of the aphis can hardly be considered, and the exceptional EM 1930 results are at present beyond explanation. The question, however, may subsequently arise as to whether Northern Spy may not differ within the clone, i.e. although morphologically identical whether some differentiation may not have occurred whereby some individual trees of Northern Spy may transmit immunity to a proportion of their offspring and others not.

The results of the reciprocal crosses between Northern Spy and Malling No. I differ considerably even when the exceptional EM 1930 families are extracted. Omitting these families, the results are: No. I × Northern Spy, 42 per cent. immune; Northern Spy × No. I, 23 per cent. immune.

It will be noted that in the crosses between the susceptible and immune forms detailed in Tables III and IV, immunes occur only in those families where the immune variety, Northern Spy, was used as parent. The immune varieties, Transparente de Croncels, Ben Davis and Carrington Red, have failed to transmit immunity to any of their offspring in the families so far raised from crossing them to susceptible forms.

TABLE V.

Immune × Immune.

Parents.	Where raised.	Year raised.	Flowers pollinated.	Fruits set.	Seeds obtained.	Seeds germinated.	Seedlings infested.	Seedlings immune.	Seedlings susceptible.
Northern Spy × Seedling No. 789 ..	M	1932	121	2	5	3	2	1	1
,, ,, 793 ..	M	1932	260	30	306	250	248	65	183
,, ,, 779 ..	M	1934	56	11	121	115	113	11	102
Seedling No. 779 × ,, 789 ..	M	1934	12	1	5	5	4	0	4
,, 789 × ,, 779 ..	M	1934	85	10	49	44	43	5	38
,, 789 × ,, 793 ..	M	1932	51	12	88	33	33	7	26
,, 789 × ,, 793 ..	M	1934	71	18	100	75	74	14	60
,, 793 × ,, 779 ..	M	1934	69	1	2	2	2	0	2
,, 793 × ,, 789 ..	M	1932	99	30	179	102	100	33	67
,, 793 × ,, 789 ..	M	1934	73	42	320	192	163	38	125
,, 793 × Northern Spy ..	M	1932	49	19	162	121	120	14	106
Northern Spy × Irish Peach ..	EM	1932	216	1	6	6	6	0	6
,, × Transparente de Croncels	EM	1932	144	2	10	10	10	1	9
,, ,, ..	EM	1933	201	8	88	56	51	7	44
,, × Reinette Zuccamaglio	EM	1932	140	5	54	48	48	17	31
,, ,, ..	EM	1933	140	11	126	101	96	16	80
,, × Winter Majetin ..	EM	1933	276	22	215	169	169	41	128
,, × Ben Davis ..	EM	1933	100	17	215	183	182	24	158
,, × Jonathan ..	EM	1934	105	2	16	10	7	4	3
Duchess of Oldenburg × Carrington Red ..	EM	1934	88	22	134	77	76	3	73
Reinette Zuccamaglio × Northern Spy ..	EM	1933	219	15	92	56	54	18	36
Transparente de Croncels × Northern Spy ..	EM	1933	166	3	23	9	8	1	7
Transparente de Croncels × Carrington Red ..	EM	1934	34	1	9	7	7	0	7

In Table V are the results obtained from inter-crossing immune varieties. The families raised from Northern Spy × Irish Peach, Transparente de Croncels × Carrington Red, Seedling No. 779 × No. 789, and No. 793 × No. 779, were all susceptible. In view of the very small number of individuals in these families, however, the results can hardly be seriously considered. In all the other families immunes occur, but there is great variation in the proportion of immune to susceptible seedlings. Thus the highest proportion of immune seedlings obtained was 33 per cent. in the family raised from crossing Reinette Zuccamaglio with Northern Spy, 27 per cent. from No. 793 × No. 789, and 26 per cent. from Northern Spy × No. 793. At the other extreme, only 4 per cent. were immune in the family raised from Duchess of Oldenburg × Carrington Red. In some of the families which have been raised from reciprocal crosses there is a wide difference in the proportion of immune seedlings, e.g. Northern Spy × No. 793 gave 65 immune to 183 susceptible, but the reciprocal cross gave only 14 immune to 106 susceptible, 26 and 11 per cent. respectively.

The seedlings, Nos. 779, 789 and 793, are three of the five immune seedlings which appeared in a family raised at Merton in 1920 from crossing Malling No. II with Northern Spy. Northern Spy × No. 789, and No. 793 × No. 779 are incompatible in a high degree, and a very low proportion of fruits set and matured in certain other crosses, e.g. Northern Spy × Irish Peach, Jonathan and Transparente de Croncels. A repetition of these pollinations, however, is necessary before it can be concluded that these cross-combinations are incompatible.

In Table VI are results obtained from selfed families. The families are small owing to the high degree of self-incompatibility. Even where apples have formed freely, as for example in selfing Malling No. VIII, very few seeds developed, and consequently very few entomological results are available.

TABLE VI.

Immune selfed.	Where raised.	Year raised.	Flowers pollinated.	Fruits set.	Seeds obtained.	Seeds germinated.	Seedlings infested.	Seedlings immune.	Seedlings susceptible.
Seedling No. 789 selfed	M	1934	104	2	2	1	1	0	1
,, 793 ,, ...	M	1934	133	1	3	2	2	0	2
,, 779 ,, ...	M	1934	24	0	—	—	—	—	—
Northern Spy ,, ...	M	1920-34	3385	24	6	4	4	1	3
Susceptible selfed.									
Malling No. IX selfed	M	1930	256	1	1	1	1	0	1
,, II ,, ...	M	1930	284	5	3	3	2	1	1
,, VIII ,, ...	M	1917-20	520	53	15	—	0	—	—

They are, however, of considerable interest. The immune variety, Northern Spy, which has been largely used in these experiments, gave susceptibles, and the susceptible Malling No. II gave an immune, in addition to an immune and susceptible respectively.

As detailed in Table VII, a number of defective seedlings appeared in several of the families raised from inter-crossing sister-seedlings derived from Malling No. II × Northern Spy, and from back-crossing them with Northern Spy. In the seedling stage the leaves of these defective seedlings were irregularly albinotic and to some extent distorted. But they soon began to develop normal leaves, and when about three months old the defective leaves had fallen, and the seedlings were indistinguishable from normal seedlings.

TABLE VII.

Parents.	No. of seeds sown.	No. of seeds germinated.	Percentage of seeds germinated.	No. of seedlings normal.	No. of seedlings defective.	Percentage of seedlings defective.
Northern Spy × Seedling No. 789	5	3	60·0	3	0	0
.. × ,, 793	306	250	81·7	240	10	4·0
,, × ,, 779	121	115	95·0	94	21	18·2
Seedling No. 779 × ,, 789	5	5	100·0	5	0	0
,, 789 × ,, 779	49	44	89·8	44	0	0
,, 789 × ,, 793	188	108	57·4	96	12	11·1
,, 793 × ,, 779	2	2	100·0	2	0	0
,, 793 × ,, 789	499	294	58·9	258	36	12·2
,, 793 × Northern Spy	162	121	74·6	103	18	14·8

The proportion of defective seedlings differs widely, varying in different families from 4 to 18 per cent. defective and, as shown in Table VII, the percentage of seed germination also varies considerably. It is not possible at the present time to say much in respect of the appearance and varying proportions of these defective seedlings, but it is probable that the surviving defectives are heterozygous for albinotic factors and that as the homozygous condition is more closely approached or reached they have a lethal effect. In this way certain albinotic genotypes would become eliminated, and this would account for the large number of seeds which in certain families fail to germinate.

In all other families raised in these experiments, the seedlings have been entirely normal, or as a rarity an occasional seedling has shown albinism. It is, however, evident (Crane and Lawrence 1933) that some of the parents used in the present experiments are heterozygous for albinotic factors, e.g. Malling Nos. VIII and IX. It is also evident that in apples several factors are concerned with albinism, and that it is a recessive character. In this respect it is noteworthy that the defective albinotic seedlings in Table VII have all appeared in inbred families.

Throughout these experiments differences have occurred in the viability of seeds, in the seed content of the fruits, and in the proportion of fruit set to flowers pollinated. Such differences are the result of degrees of sterility and incompatibility, and it is possible that in some cases they may affect segregation and the proportion of susceptible to immune seedlings.

GENETICAL DISCUSSION.

Although at this stage of the investigations it is not desirable to attempt a detailed genetical discussion, the available results show several features of interest.

The offspring from reciprocal crosses between Malling No. IX (susceptible) and Northern Spy (immune) were all in some degree susceptible. Small families raised from Lane's Prince Albert and Malling No. XIII × Northern Spy were also all susceptible. In families raised from other susceptibles, for example Malling No. I and No. II, crossed with the same immune parent, a considerable proportion of the seedlings were immune, and further different susceptibles when crossed with the same immune (Northern Spy) have given different proportions of immune seedlings, such differences ranging from 4 per cent. to 46·6 per cent. It is therefore evident that the susceptibles are genetically of different kinds. It appears that some take part in the hereditary transmission of immunity, and that some do not. Further, amongst those susceptibles which do take part, some contribute to the transmission of immunity to a greater extent than others.

Similarly the immunes which have been used as parents differ considerably in respect to the proportion of immune seedlings obtained. Thus in families from crosses between susceptibles and varieties like Ben Davis and Carrington Red, no immunes occurred, and again amongst families raised from immune × immune the results have varied widely. In a few small families raised from inter-crossing immunes the offspring have all been susceptible, and in families of moderate size the proportion of immunes has varied from 4 to 33 per cent. In the varieties Irish Peach, Ben Davis, Reinette Zuccamaglio, Transparente de Croncels and Duchess of Oldenburg, immunity to the Woolly Aphis is not of quite so high an order as it is in the varieties Northern Spy, Winter Majetin, Carrington Red and Seedlings Nos. 779, 789 and 793. But even in families raised from inter-crossing the latter varieties and seedlings, which are phenotypically similar in respect of immunity, the results have varied considerably. Thus Northern Spy × Winter Majetin gave 24 per cent. immune, Northern Spy × No. 793, 26 per cent., Northern Spy × No. 779, 9 per cent., and in families raised from inter-crossing the immune seedlings Nos. 779, 789 and 793 the proportion of immunes obtained ranged from 11 to 27 per cent. These quantitatively different results with respect to the inheritance of immunity show that the immunes, like the susceptibles, are genetically of different kinds.

Where families raised from reciprocal crosses have been investigated the proportion of immunes is in some cases the same, or the divergence has not been significant, but in others they have differed considerably. As shown in Table VIII, such differences have occurred in reciprocal crosses between susceptible and immune parents (Malling No. I × Northern Spy) and also in families where both parents were immune (Northern Spy × Seedling No. 793).

TABLE VIII.

Parents.	No. immune.	No. susceptible.	Percentage immune.
Susceptible × Immune and Reciprocal :			
Malling No. II × Northern Spy	*101	221	31·3
Northern Spy × Malling No. II	92	156	37·1
Malling No. I × Northern Spy	78	108	41·9
Northern Spy × Malling No. I	70	226	23·6
Immune × Immune :			
Northern Spy × Transparente de Croncels ..	8	53	11·4
Transparente de Croncels × Northern Spy ..	1	7	12·5
Northern Spy × Reinette Zuccamaglio ..	33	111	22·9
Reinette Zuccamaglio × Northern Spy ..	18	36	33·3
Seedling No. 793 × No. 789	71	192	27·0
Seedling No. 789 × No. 793	21	86	20·0
Northern Spy × Seedling No. 793	65	183	26·2
Seedling No. 793 × Northern Spy	14	106	11·6
Seedling No. 793 × No. 779	5	38	11·6
Seedling No. 779 × No. 789	0	4	0

* In these totals the exceptional families raised at East Malling in 1930, in which no immunes appeared, are not included.

In those cases where wide reciprocal differences occur, in one direction of crossing the proportion of immune seedlings is approximately twice as large as in the other. This draws attention to a possible influence of the cytoplasm affecting the transmission of immunity. But the higher proportion of immunes occurred sometimes when Northern Spy was used as the female and sometimes when it was used as the male parent. It is obvious therefore that cytoplasmic influence does not afford a direct explanation of these reciprocal differences, and it is more probable that they arise through linkage—possibly between sterility or incompatibility and immunity factors.

Another unusual result in these experiments is that the proportion of immunes obtained is often as large, and frequently much larger in crosses between susceptibles and immunes, than is obtained in families raised from immune × immune. Thus Bristol O.F.5 (susceptible) × Northern Spy gave 46·6 per cent., Malling No. I × Northern Spy gave 41·9 per cent. and Malling No. II × Northern Spy and reciprocal gave 31·3 and 37·1 per cent. immune respectively.

From crossing immune with immune the highest proportion of immune obtained was 33·3 per cent. (Reinette Zuccamaglio × Northern Spy). The next highest was from inter-crossing the two immune sister-seedlings, Nos. 793 and 789, which gave 27 per cent. immune and No. 793 × Northern Spy, 26·2 per cent.

The principal results, and the conclusions arrived at in this discussion, can be epitomized as follows: (1) The susceptibles are genetically of different kinds; some possess factors or genes concerned with the determination of immunity, and some do not. (2) Amongst the former kind, some susceptibles play a larger part in the transmission of immunity than others. (3) There is a graduation in the inheritance of susceptibility (Tables I and IA). (4) All the immunes used are heterozygous. (5) The immunes, like the susceptibles, are of different kinds. (6) In the crosses so far made, Northern Spy has a higher value in respect of the transmission of immunity than any of the other immune varieties used. (7) Immunes selfed give susceptibles (Table VI). (8) Susceptibles selfed give immunes (Table VI). (9) Some reciprocal crosses give approximately similar, other dissimilar results.

Collectively the results indicate that the hereditary behaviour of immunity is determined by and dependent upon a certain balance of genetic factors, and that it is governed by a number of genes the action of which is in part complementary, and in part cumulative. On the basis of these conclusions it would be possible tentatively to postulate a scheme of inheritance which would accord closely with the facts, but it is doubtful whether it would be worth while at this stage. In particular, further results from inbreeding immunes and susceptibles are desirable, especially from inter-crossing susceptibles which appear to possess factors concerned with immunity.

It may be recalled here, that although from the initiation of the experiments the so-called purely genetical and entomological aspects have received careful consideration, one of the main objects of the investigations is an attempt to combine immunity with other desirable characters. Indeed it was largely owing to this economic aspect that it became possible to obtain the facilities to conduct the experiments on a comparatively large scale. Consequently but few results are at present available from inter-breeding susceptibles, but since it now appears probable that immunes may arise from susceptibles it is intended to inter-cross them more extensively, and this may materially assist in an interpretation of the results.

Although precise knowledge of the frequency of immunity amongst the numerous rootstocks and varieties of apples in cultivation is limited, general observations indicate that only a small proportion are immune to the attack of Woolly Aphis. In these experiments, all the immunes used have proved to be heterozygous, and such forms as Bristol O.F.5, Malling No. I, etc., although themselves susceptible, appear to carry factors concerned with immunity. It therefore appears probable that the immunes have arisen from the susceptibles, possibly by an additive or reductional process which has enabled the factors concerned to reach a condition whereby immunity is expressed in the phenotype.

The complexity of the results is in some respects comparable with that previously encountered in genetical studies in apples. Compare, for example, Crane and Lawrence (1933-34) and Heilborn (1935). In these, as in the present studies, difficulties have occurred in deciding dominance. When a number of cumulative factors govern the same character, the expression of dominance is essentially variable. Certain balances may suggest that a character is recessive, whereas others point to dominance.

In apples, although from some points of view breeding work may appear to have been somewhat considerable, asexual reproduction is almost the rule, and compared with many plants sexual reproduction has been very limited. Owing to the practical difficulties of breeding apples on a really large scale, and also to their complex nuclear constitution (Darlington and Moffett 1930, Moffett 1931) it may take a considerable time to approach or obtain forms homozygous for immunity. But although such forms would be of importance to the geneticist, the ease of vegetative reproduction enables heterozygous forms to be of practical value.

CHARACTERS AND COMPARATIVE ANALYSIS OF IMMUNE SEEDLINGS.

Since the experiments began, 573 seedlings have proved to be immune from the attacks of the Woolly Aphis and have been passed out by the Entomological Section for testing as to their suitability as rootstocks. Details of the parentage of these immune seedlings are given in Table IX.

These tests are designed to ascertain (a) the ease with which the seedlings can be reproduced by vegetative means and (b) the influence which they exert, as rootstocks, over the scion variety with which they are worked. The ease with which a rootstock can be reproduced by the methods of vegetative propagation forms one of its most important attributes as a rootstock. The seedlings are therefore planted out in the field and subjected to the method of vegetative propagation by which the apple rootstocks of commerce are commonly raised. By this method, known as "stooling", the seedlings are cut down to within a few inches of soil level and mounded up with soil. Shoots arising from buds beneath the mound become rooted at their base and when severed from the stool are planted out to form new individuals. The response of certain of these families of immune seedlings to this method of propagation is shown in Table X.

TABLE IX.

Immune Seedlings now undergoing trial.

Raised at Merton.		Raised at East Malling.	
Family.	No. of immune seedlings.	Family.	No. of immune seedlings.
No. I × Northern Spy (2 families)	57	Northern Spy × No. I (2 families)	46
Northern Spy × No. I	26	Northern Spy × No. II (2 families)	72
No. II × Northern Spy (2 families)	69	No. II × Northern Spy	26
Northern Spy × No. II (3 families)	32	Northern Spy × No. VIII	2
No. II selfed	2	Northern Spy × No. XII	33
Northern Spy × Immune Seedling No. 789	1	Bristol O.F.5 × Northern Spy	70
Northern Spy × Immune Seedling No. 793	46	Northern Spy × Reinette Zuccamaglio	17
Northern Spy × Immune Seedling No. 793	19	Northern Spy × Transparente de Croncels	1
Immune No. 789 × Immune No. 793	7		
Immune No. 793 × Immune No. 789	33		
Immune No. 793 × Northern Spy	14		

As may be seen, the families of seedlings differ somewhat widely in their response to this method of vegetative propagation.

At the end of several years it is found possible to make a selection of those individuals which have shown consistently good performance throughout this propagation trial. These are then reproduced in sufficient quantity to allow for the necessary replications demanded by modern methods of plot lay out and are then budded with a scion variety. So far Lane's Prince Albert has been the variety employed since it is reputed to mature early. While the

TABLE X.

Rooting of Immune Seedlings grown as stools.

Parents.	1934.			1935.		
	Good.	Moderate.	Poor.	Good.	Moderate.	Poor.
Northern Spy × No. I	5	2	1	2	2	4
Northern Spy × No. II	0	0	1	0	0	1
No. II × Northern Spy	0	0	1	0	0	1
No. IX × Northern Spy	0	1	0	0	1	0
Northern Spy × No. VII	0	0	1	0	0	1
Northern Spy × No. XII	1	0	0	1	0	0
No. XV × Northern Spy	1	1	0	1	1	0
Northern Spy × No. XV	3	0	0	2	0	1
	10	4	4	6	4	8

earlier trials were necessarily somewhat incomplete, as our knowledge of the technique of plot lay out has improved and as a greater range of material has become available, it has been possible to lay out trials in randomized blocks in which such factors as soil differences and positional influences have been fully taken into account.

Since it has not been found practicable to devote large areas to such trials, a technique has been devised whereby preliminary deductions can be drawn as to the capacity of these rootstocks for imparting vigour and precocity to the scion variety with the minimum expenditure of ground. The trees are grown in rows 5 to 6 feet apart and 18 to 24 inches apart in the rows. The trees are left as far as possible completely unpruned and, if necessary, are supported by wires after the manner of cordons. As the trees, in the course of their development become too crowded, alternate trees are removed and the plots are so arranged that this removal does not affect the relative proportions of trees on the different rootstocks remaining. Annual measurements of the new wood growth, diameter of the stem at three inches above the union, are made and the number of blossom trusses and the number and weight of the fruits are recorded, in addition to which notes on such characters as anchorage of the roots, and resistance to disease and insect pests are made.

Although, as has been indicated, a large number of immune seedlings are now undergoing trial, only three, derived from a family of No. II × Northern Spy* raised at Merton in 1920, and known as Merton Nos. 778, 789 and 793, have yet reached a stage at which it is possible to make any deductions as to their possible value as rootstocks. Details of the new wood growth, diameter of stem, number of blossom trusses and number and weight of fruits annually during five years are summarized in Table XI. These data have been obtained from a preliminary trial budded with Lane's Prince Albert in 1930. As may be seen from the Table, trees on these three selections were very similar to one another during their first three years, both in vigour as expressed in new wood growth and increment of stem diameter and in precocity as expressed by blossom and fruit production. By the fourth year a considerable difference was observable in the amount of new wood growth made by trees on the three selections, although there was little difference in the number of blossoms and fruits borne. By the fifth year these differences in vigour had become much accentuated and the trees on these three seedlings had formed a series in which those on No. 793 were the least vigorous and those on No. 789 the most vigorous. Corresponding differences in productivity have also manifested themselves, trees on the least vigorous selection being considerably the most productive of both blossoms and fruit and trees on the most vigorous selection being the least productive. Since comparable trees on neither Northern Spy nor Malling No. II (Doucin) were available in this preliminary trial, it is not possible to say how the behaviour of these seedlings as rootstocks compares with that of the parent varieties. As may be seen from the Table XI trees worked on Malling No. IX, Jaune de Metz, the most dwarfing and precocious in its influence over the scion variety, of any of the Malling series of "Paradise" apple rootstocks, were much less vigorous and more productive of both blossoms and fruit than those on the three selections of No. II × Northern Spy. In fact, over the five years during which this trial has been studied, trees on No. 789, the most vigorous of these selections, has made rather more than three times as much wood growth, rather less than half the blossom trusses and borne little more than one-fifth of the fruits borne by trees on Malling No. IX. The work of Hatton (6) showed that Malling No. II and Northern Spy were very similar in their influence upon the scion variety Grenadier, although trees on the latter were rather less vigorous and less productive of both flowers and fruit at the time when the report was written. Both are decidedly more vigorous and less productive than Malling No. IX, at least in their early years. Since Hatton's report was published the trees on No. II have grown much more vigorously than those on Northern Spy.

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* Described as Northern Spy × No. II in previous reports by Le Pelley, Massee and Tydeman.

The above account of the behaviour of trees of Lane's Prince Albert worked upon these selected rootstocks can only be regarded as tentative. The trees reported on have been growing for only five years and their later behaviour may make it necessary to modify any deductions which might be made from their behaviour at the present stage. Furthermore, the trial, which was the first of its kind to be laid down at East Malling, was very incomplete. Not only were the trees not randomized in any way but control varieties necessary for the full interpretation of the results are lacking. In the light of the experience gained, it has now been possible to lay down more complete trials and further data are accumulating. A fuller account of these trials may be found elsewhere (15).

During the autumn of 1935, the trees of a preliminary trial consisting of 138 three-year-old trees of Lane's Prince Albert worked on two selections, Nos. 779 and 789 from the family Malling No. II × Northern Spy, together with Malling Nos. IX, II and XII, having been superseded by a more complete trial, were excavated. Care was taken to retain the root systems undamaged in order that detailed records could be obtained. An analysis of these root systems is given in Table XII. In general, it might be said that the root systems of trees on these two selected seedlings were entirely different.

The root systems of those on No. 789 resembled very closely those of trees on Doucin, Malling No. II and consisted of coarse fangy roots spreading out almost horizontally and almost completely devoid of fibre. As may be seen from Table XII, fibre comprised on the average only 2½ per cent. of the total weight of these systems. The root systems of trees on No. 779 were an almost complete contrast. The main roots were less coarse although inclined to be horizontal and spreading with abundant fibre more particularly around the collar. Actually fibre comprised 8·8 per cent. of the total weight of the root system. As the figures in Table XII indicate, the root systems of trees on No. 789 are very similar to those on Malling No. II. While comparable trees, worked on Northern Spy, the other parent of these seedlings, were not available

Table XI.

Average new wood growth, diameter of stem, number of blossom trusses, number and weight of fruits per tree.

Lane's Prince Albert on three immune rootstocks (Northern Spy × Malling No. II).

Root-stock.	Year.	Number of Trees.	Wood Growth.	Diameter of Stem. Annual Increase.	Number of Blossom Trusses.	Number of Fruits.	Weight of Fruits.
			cms.	cms.			ozs.
No. 793	1st	47	109·4	1·00	0	0	0
	2nd		607·2	1·00	0·1	0	0
	3rd		1,192·4	0·66	12·0	2·4	13·0
	4th		1,297·2	1·00	26·1	3·0	16·0
	5th		1,549·3	1·00	156·8	14·7	48·0
	Total ..		4,755·5	4·66	195·0	20·1	77·0
No. 778	1st	15	106·1	0·99	0	0	0
	2nd		588·2	1·11	0·1	0	0
	3rd		1,281·4	0·75	19·3	6·0	25·3
	4th		2,074·9	0·88	45·2	3·5	16·0
	5th		1,896·8	1·55	125·8	9·7	38·0
	Total ..		5,947·4	5·28	190·4	19·2	79·3
No. 789	1st	28	104·3	0·94	0	0	0
	2nd		539·0	1·10	0	0	0
	3rd		1,261·4	0·68	10·4	3·5	20·1
	4th		2,223·5	1·34	27·4	3·5	16·1
	5th		2,710·8	1·40	76·1	2·1	7·5
	Total ..		6,839·0	5·46	113·9	9·1	43·7
No. IX	1st	43	99·4	0·90	0	0	0
	2nd		233·5	0·72	4·0	0·4	2·5
	3rd		542·8	0·38	49·5	5·5	29·3
	4th		722·8	0·56	69·2	13·9	72·2
	5th		372·3	0·38	132·7	23·3	65·5
	Total ..		1,970·8	2·94	255·4	43·1	169·5

for excavation, observations upon other trees indicate that it has a root system consisting of a large proportion of fibre. More detailed descriptions of these root systems may be found elsewhere (16).

SUMMARY.

1. The life cycle of the Woolly Aphis, *Eriosoma lanigerum* (Hausm.), is outlined, and the hereditary behaviour of the apple in respect of immunity to its attack is described, and the term "immunity" as used in this paper is defined.

2. An account is given of the entomological technique used in testing for resistance and immunity, and of preliminary physiological investigations on the underlying causes of immunity.

3. A genetical analysis is made of the families raised from crossing established varieties of apples with a number of forms commonly used as rootstocks. The seedlings have been derived from susceptible × susceptible, immune × immune, susceptible × immune and a few small families from selfing immune and susceptible forms. A total of 3,758 seedlings have been raised, entomologically investigated, and their susceptibility or immunity determined.

4. It is tentatively concluded that the immunity to attack is determined by and dependent upon a certain balance of genetic factors, and that it is governed by a number of genes the action of which is in part complementary and in part cumulative.

5. A preliminary account is given of the characters of some of the immune seedlings.

The photographs reproduced as Figs. 1, 2 and 3 were taken by Dr. Massee and Figs. 4 and 5 by Miss K. Cornford.

Table XII.

Analysis of Root Systems. Three-year-old budded trees.

Root-stock.	Average Depth of Roots.	Average Spread of Roots.	Average Number of Main Roots.	Total Average Weight of Root System.	Average Weight of Stock Stem.	Average Weight of Coarse Roots.	Average Weight of Fibre.	Weight of Fibre as per cent. of Total Weight of Roots.
	cms.	cms.		grams.	grams.	grams.	grams.	
No. 789	35·4	69·0	3·8	604·6	331·7	266·1	6·8	2·49
No. 779	36·2	81·6	3·3	526·5	311·4	196·2	18·9	8·79
No. IX	29·9	59·9	2·5	—	—	—	—	—
No. II	36·0	72·7	3·7	445·9	249·7	189·1	7·1	3·62
No. XII	41·2	88·8	5·9	—	—	—	—	—

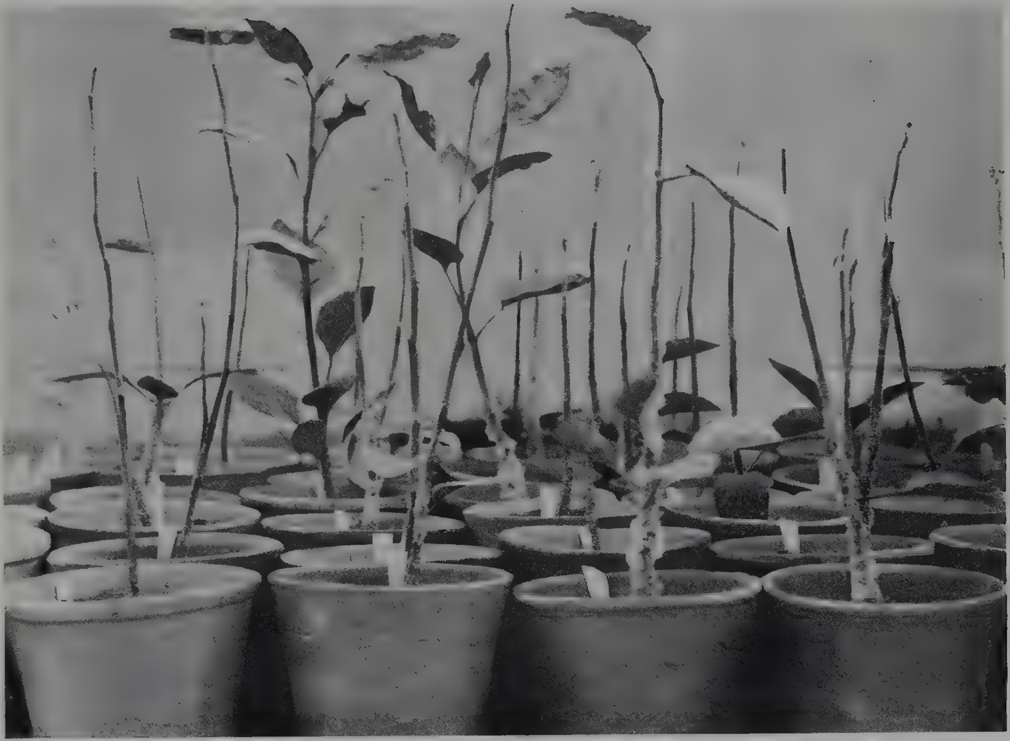

FIG. 1. Showing method of growing and testing of Seedlings for immunity or susceptibility to the attack of the Woolly Aphis.

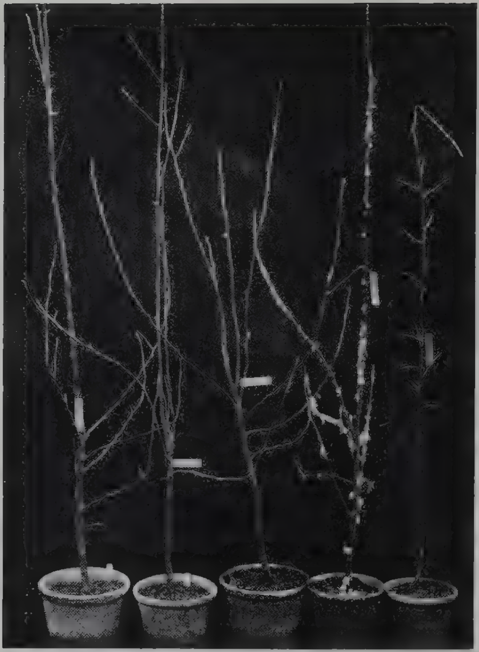

FIG. 2. Seedlings showing immunity and degrees of susceptibility.
From left to right: (1) immune, (2) very slight infections, (3) small colonies and small galls formed, (4) severe infestations, (5) seedling killed by the severity of the attack.

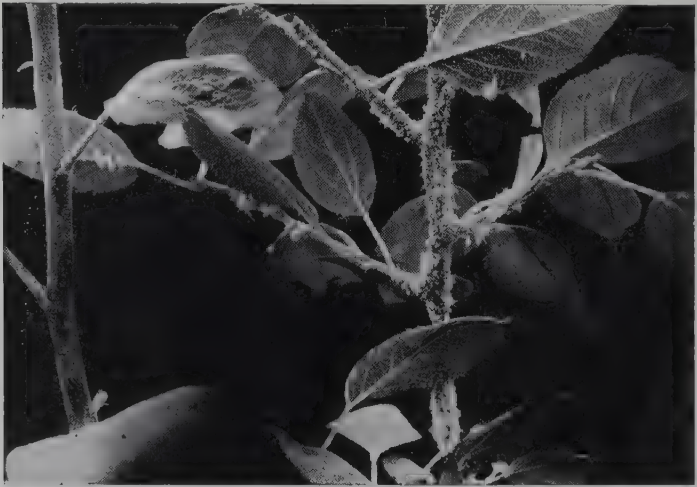

FIG. 3. Apple Seedlings: Left, immune; Right, susceptible to Woolly Aphis.
Raised from Malling No. II (susceptible) × Northern Spy (immune).

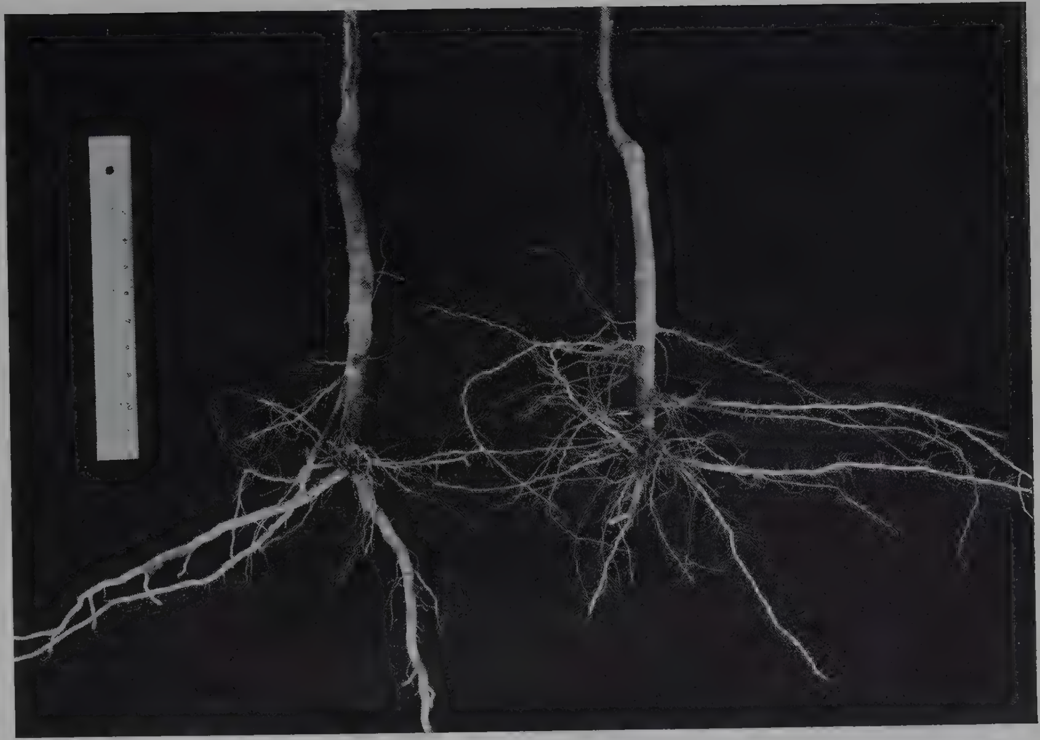

FIG. 4. Root systems of maiden trees of Lane's Prince Albert on (Left) Malling No. II (Doucin) and (Right) Northern Spy.

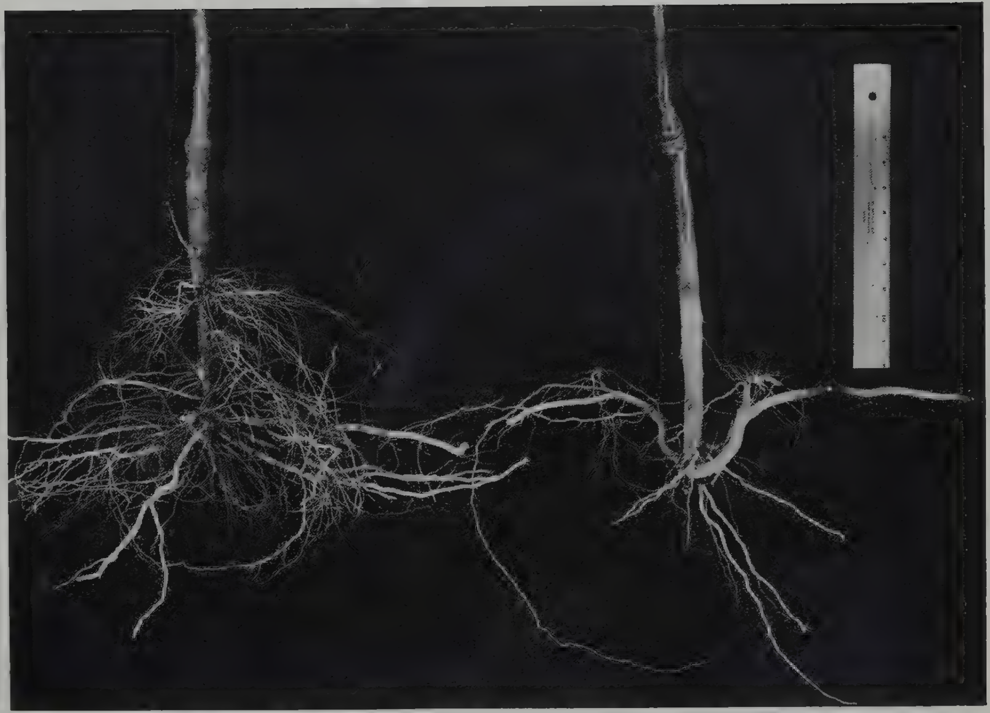

FIG. 5. Root systems of maiden trees of Lane's Prince Albert on two selected immune rootstocks of No. II × Northern Spy. (Left) Merton No. 779, (Right) Merton No. 789.

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ENVIRONMENT AND ITS INFLUENCE UPON DECIDUOUS FRUIT PRODUCTION

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THE belief is firmly held by fruit-growing pioneers in South Africa that there has been a deterioration in the quality of Cape fruit and that it does not carry as well as it used to do in former years. In support of this contention there have been complaints from England, especially since 1925, about woolliness in peaches, bladderiness and leatheriness in plums and scald in Bon Chrétien pears. During the past season there were even more serious complaints from the trade; dissatisfaction was reflected in the sale of Bon Chrétien pears, Peregrine peaches and Kelsey plums, and the prices obtained for these fruits at times were distinctly low.

For this lack of condition various theories have been advanced. Some have held that the acidity of the soils has increased with the passage of time and that fruit quality has deteriorated as a result of this increase of soil acidity. Others have contended that a lack of soil moisture during the growing season has been a major factor impairing fruit quality. Most people concerned are in full agreement that the soils in both respects are far from ideal, and almost every grower has given serious attention to orchard improvement by applying liberal amounts of lime and by the use of irrigation, wherever possible, to make up for the deficiencies of rainfall in recent years. These measures have unquestionably had a good effect upon the quantity and quality of fruit produced. But these treatments notwithstanding, and in spite of increased knowledge of tree requirements as regards pruning, pollination and soil treatment, yields have fluctuated widely and these fluctuations have been particularly violent since 1925. These variations in yields are a matter of grave concern as it raises the question of the suitability of some areas for certain deciduous fruit trees. It is imperative, therefore, that the underlying cause for unsatisfactory tree performance should be determined with a view to applying remedial measures, should such measures be found to be practicable.

A review of the environment of the tree may point to a major factor which could account for fluctuating tree yield. Environment embraces the whole constellation of growth factors which may be summarized as placed in four main groups, no effort being made to arrange the groups in order of importance.

Group 1. Atmospheric—Radiation (temperature and light) and humidity.
Group 2. Biotic—Diseases and pests.
Group 3. Edaphic—Soil texture, acidity, fertility and moisture.
Group 4. Cultural—Rootstocks, planting systems, pruning, cultivation, etc.

At the outset it should be stressed that each of these factors plays a part in tree development, and that it is the inter-action of these factors which finally governs growth. The reaction of the tree to any one factor is modified to some degree by the presence of every other factor of the environment. As there are many possible combinations of these factors with corresponding variable effects upon the tree, it follows that it may be difficult to single out particular forces which may be considered to play a dominant role. This particularly applies to the fruit tree, which, owing to its growth nature, does not lend itself to carefully planned pot-experiments, where, for the purpose of experiment, one factor only of the environment would be allowed to vary. The difficulties of such laboratory technique obviously are insurmountable. For the same reasons field experiments have had to be ruled out, and use has had to be made of the field survey method of research in order to arrive at any conclusions. This has consisted of a study of tree behaviour of a considerable number of varieties in experimental orchards under the climatic conditions which prevail at Stellenbosch. For purposes of comparison and with certain selected trees, varietal behaviour has been studied in widely removed districts where the environment has differed considerably.

Hitherto much attention has been given to the important soil, biotic and cultural aspects of the environment and all farmers know to their cost how their crops may be limited by unsuitable soil conditions, by diseases and pests, and by faulty cultural practices. These factors have been stressed, and, since their importance is recognized, it may be profitable to explore some of the conditions of the atmosphere to determine what role they play in deciduous fruit production. Climate has been the subject of study at Stellenbosch for some years and while this subject is too wide to cover so briefly and, while various factors such as temperature and humidity are closely inter-related and should be dealt with in conjunction, the results of the study of air temperatures have been so striking that some of the conclusions arrived at will here be presented. The single factor of maximum temperatures during the winter months will be dealt with mainly, in order to indicate to what extent high temperatures are limiting to the fruit industry.

In the United States, particularly in Southern California, where fruit is grown under conditions very similar to those in South Africa, an effort has been made to determine the critical temperature above which the peach and other fruit varieties susceptible to winter heat injury fail to crop. Weldon* has stated that, if the mean temperatures for the two mid-winter months, December and January, are above 49·5° F., a poor fruiting season may be expected. The mean temperature, a composite figure obtained by adding the maximum and the minimum temperatures and then dividing by two, gives no indication of the extremes of temperature which prevail during any season. For the purpose of this investigation, the maximum temperature seems more significant and the following graphs show the clear relationship which exists between yield on the one hand, and the maxima temperatures prevailing during May, June, July and August of the preceding winter on the other hand. Fig. 1 represents the tonnage of dried prunes delivered at a leading pack-house in the Western Province and mean maxima temperatures for Elsenburg, which is situated

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* *Fifteen Years Study of Delayed Foliation of Deciduous Trees in Southern California.* Geo. P. Weldon. Monthly Bulletin, Dept. of Agric., Calif. 1934, 23, 160-81.

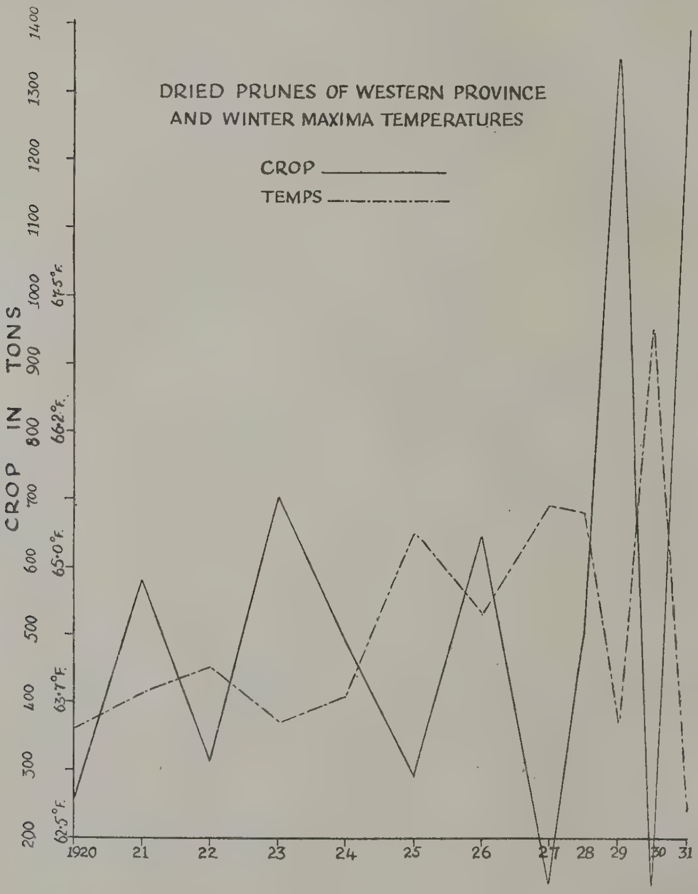

Fig. 1.

within the prune growing area. Prior to 1931, prunes were almost exclusively dried and the tonnage may be taken as a fair indication of the size of the crop in the different years. The trees were unsprayed as they were largely free from diseases, and were practically unpruned. These yields, therefore, are singularly free from fluctuations due to attacks from pests or to differential pruning treatment, and, as the crops were produced in different districts on widely differing soils, the soil as a factor influencing yield may be disregarded.

It will be noted that when the maxima temperatures for the winter months were high the crop was poor and conversely, when the temperatures were low there was an abundant yield ; also that the critical temperature appears to be near 64·5° F. Even more convincing is the relationship of yield to temperature in the following graph (Fig. 2) which shows the total tonnage of fruit shipped from Franschhoek, consisting mainly of white fleshed peaches, Japanese plums and Bon Chrétien pears. High peaks of temperature show a corresponding low yield and vice versa. Temperatures of 64° F. have produced good crops while 66° F. and higher have reacted unfavourably upon yield. Here also the critical temperature appears to be in the vicinity of 65° F. for the four winter months.

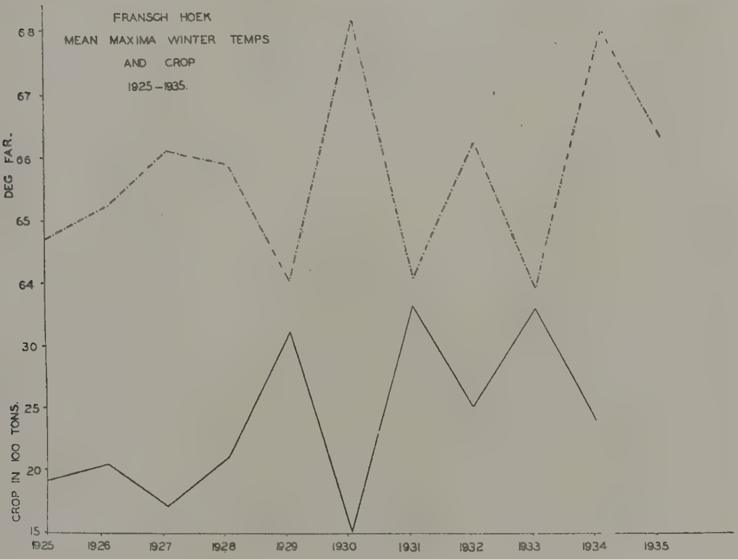

FIG. 2.

Assuming that the critical temperature is approximately 64·5° F., an examination of the temperature record for some station over a period of years will show how often such temperatures have obtained in the past. This will enable a judgment to be made as to how often winter temperatures have been unfavourable and give a rough approximation of what may be expected in years to come. Fig. 3 represents mean maxima temperatures for the four winter months from 1903 to 1935 at Elsenburg. For the 32 year period there were 15 seasons with winter temperatures above 64·5° F. and 17 years below this temperature limit. On this basis and on the average, at Elsenburg, over a considerable period, low crop yields due to high temperature almost every other year may be expected. The statement should be carefully considered by those contemplating planting orchards where the winter temperatures are as high or higher than at Elsenburg. It should be noted by those also who have varieties which are susceptible to winter heat injury, and which cannot be treated successfully to induce regular cropping. In this connection peach varieties susceptible to injury may have to be top-worked to non-susceptible varieties. These high winter temperatures account in a very large measure for the relatively low average annual tree yields of the Western Province to which attention has previously been drawn.

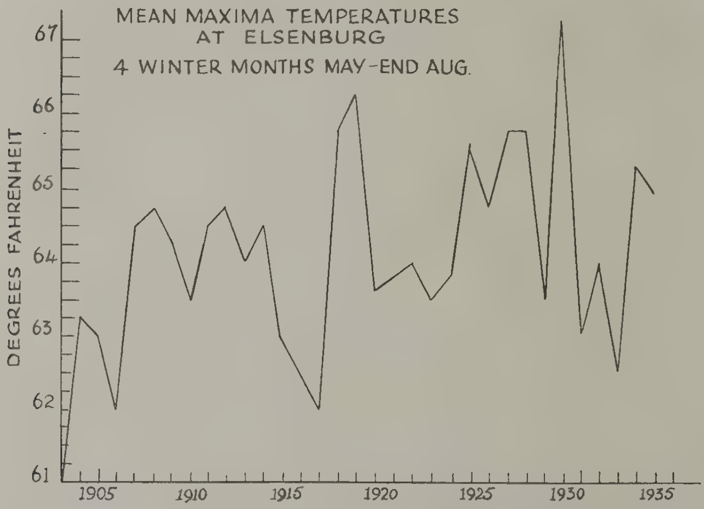

Fig. 3.

Weldon quotes Marysville and Merced (mean maxima temperatures for the four winter months 58·6° and 59·8° F. respectively) as places in California where the winters are favourable to deciduous fruit trees and Los Angeles and Pomona (mean maxima winter temperatures, November, December, January and February, 65·9° F. and 66·2° F. respectively) where delayed foliation occurs. This provides a useful basis of comparison and to some extent determines what places in South Africa may be expected to be free from injury from high winter temperatures. Fig. 4 shows the mean maxima winter temperatures for different stations in California and in South Africa from which it may be concluded that only Harrismith, Maseru and Johannesburg have winter temperatures which nearly correspond to the temperatures of Marysville and Merced. Almost all stations quoted in the Western Province have mean maxima temperatures of 64° F. and higher and are therefore exposed to loss from "delayed foliation". Graaf Reinet in the Eastern Province, Riversdale and Oudtshoorn in the South-Western district, have winters which are considerably warmer.

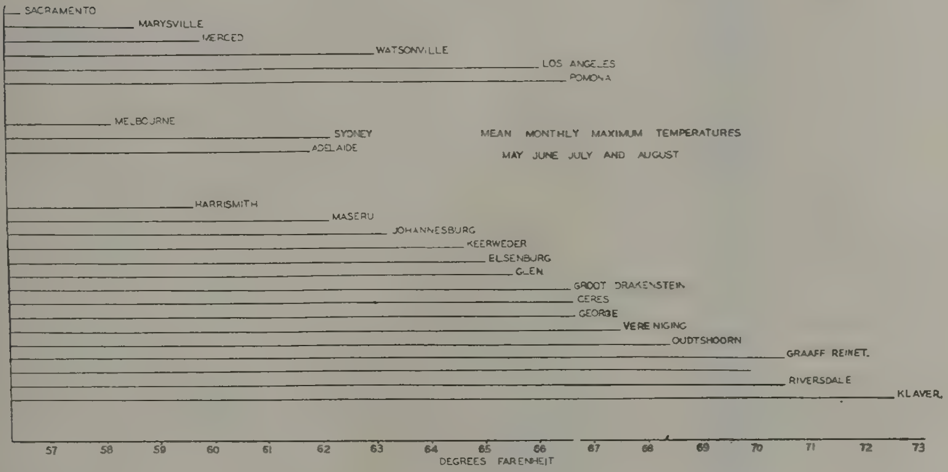

FIG. 4.

Unfortunately no temperature details are available for established fruit-growing areas at high altitudes in the Cape Province where there would be less danger of loss from high winter temperatures. (In the absence of published figures of temperatures over a considerable number of years, use has been made of available Blue Books of the Meteorological Office. These refer only to the years 1926, 1927 and 1929, and owing to the shortness of this record, the value of this graph is limited. This diagram nevertheless serves to indicate the mild winters which prevail in South Africa by comparison with some fruit growing centres overseas; and in this connection the relatively low winter temperatures for three places in Australia are significant.)

In the diagram showing winter temperatures at Elsenburg for the thirty-two-year period (Fig. 3), there appears to be a distinct trend for the winters to become warmer from 1917, and particularly from 1928 onwards. The lowest winter temperature of the four months was 60·5° F. in 1903 and the highest was 67·5° F. in 1930, a very considerable range and, in the light of present knowledge, a range of very great significance to the fruit grower. Since a difference of even one degree in temperature in the mean maxima for the four winter months above or below 64·5° F. may make a difference in the crop and, furthermore, since there appears to be a tendency for South African winters to become increasingly warmer, it is desirable to know more about the temperature trend of the winter months. Accordingly a map has been prepared showing mean maxima winter temperatures for the Royal Observatory, Cape Town, for ten-year periods from 1875 onwards. Fig. 5 shows the winter temperatures which prevailed during the following periods: 1876 to 1885; 1886 to 1895; 1896 to 1905; 1906 to 1915; 1916 to 1925; 1926 to 1935.* During the first two ten-year periods the winter temperatures were low, during the ten years, 1896 to 1905, the mean maximum temperature rose from 63·2° to 64·0° F. During the next decade the mean temperature rose to 64·3° F. followed in the next period by a slight drop to 63·9° F. The final period, 1926 to 1935, shows an amazing increase of the mean maximum temperature to 65·5° F. In view of the close relationship between high winter temperatures and low yield of fruit of indifferent quality, it seems reasonable to assume that this big rise in winter temperature in the last ten years has been a major factor in causing the various ills which of late have fallen to the lot of the fruit grower. The diagram shows the very distinct trend for winters to become warmer, and working on the theory of fluctuating temperature cycles, it may be that the swing of the pendulum may soon be in the reverse direction providing the colder winters and better fruit seasons of former years. On the other hand, the end of the heat cycle may not have been reached yet and it is well to be prepared for either situation as it may arise.

Next, the effect of high temperatures upon the physiology of the tree must be considered. By this time growers are acquainted with the abnormal growth and fruiting of susceptible peaches, plums, pears and apples after a warm winter, a condition described as " delayed foliation ". Observations upon tree behaviour as affected by local climate may however not be out of place and serve to show the striking differences in tree growth in South Africa as compared with that of similar trees grown in colder countries.

The behaviour of the fruit tree during the blossoming period serves a good purpose as a basis of comparison and the figure indicates the length of the blossoming period of deciduous fruit trees at Stellenbosch. It also gives the order of blossom of some of the more important varieties. Pears, apples, peaches and plums in the year 1934 required at Stellenbosch on the average

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* Data kindly supplied by H. M. Astronomer.

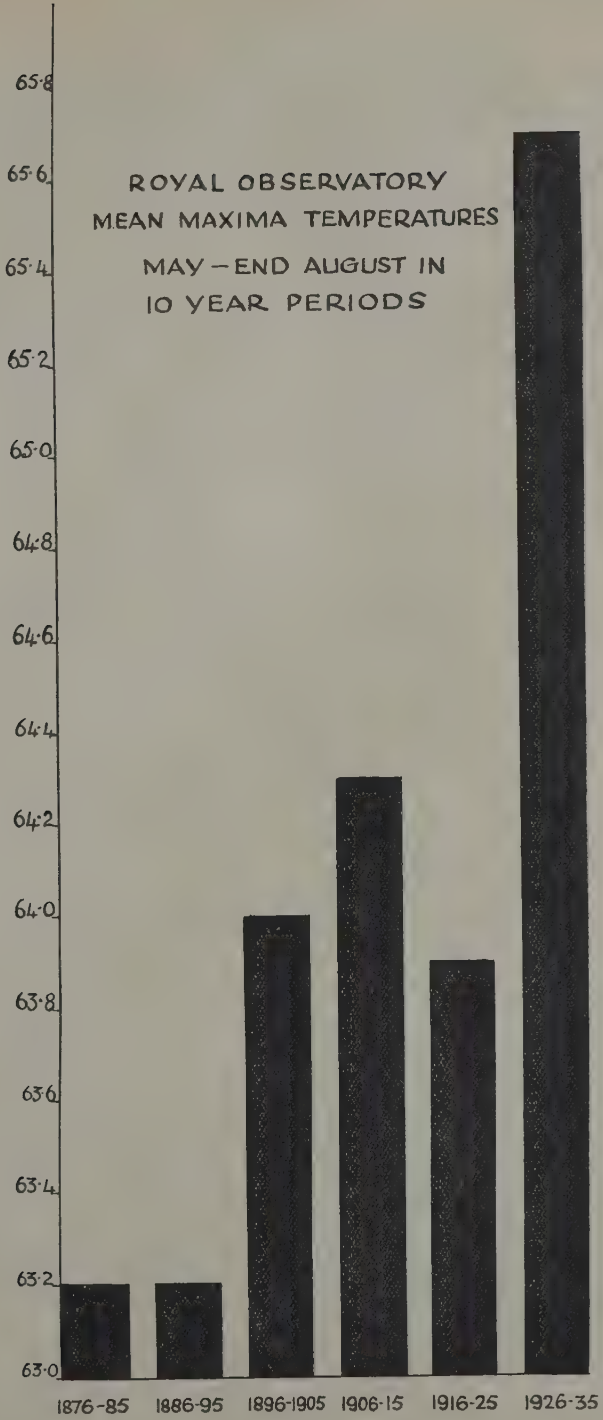
ROYAL OBSERVATORY
MEAN MAXIMA TEMPERATURES
MAY – END AUGUST IN
10 YEAR PERIODS
65·8
65·6
65·4
65·2
65·0
64·8
64·6
64·4
64·2
64·0
63·8
63·6
63·4
63·2
63·0
1876-85
1886-95
1896-1905
1906-15
1916-25
1926-35

FIG. 5.

four weeks for each kind of fruit to complete the blossoming process and the blossoming season lasted over a period of three and a half months (from middle of August to the end of November). As a contrast, at Illinois, U.S.A., the average length of bloom for each kind of fruit is eight days, and the length of the blossoming season of all fruit varieties, beginning with the first blossom up to the fall of the last bloom, is twenty-two days.

TABLE I.

The blossoming season of some commonly grown fruit varieties.

Late August.	First week in September.	Second week in September.	Third week in September.	Fourth week in September.	First week in October or later.	Kind of Fruit.
Almonds in variety						Almonds.
Alpha	Royal					Apricots.
	Early Dawn	Schoongezicht		Briggs R. May	High's Early Canada	Peaches.
	Mamie Ross Vaal Mammoth		Constantia Crimson Galande Early Alexander	Peregrine		
			Elberta	Goodman's Choice		
			Pucelle	Tuscan Cling Phillips Pullars Cling		
	Methley Kelsey	Formosa Santa Rosa Wickson	Gaviota	d'Agen		Plums.
		Le Conte	Louise Bonne	Packman's Triumph	Glou Morceau Bon Chrétien	Pears.
		Kieffer				
			Magnate	Winter Nelis	Beurré Bosc Clapp's Favourite Beurré Hardy	
			Gravenstein		Rome Beauty	Apples.
				Ben Davis		
			Cleopatra	Cox's O.P.		
			Commerce	Rokewood		
			W. W. Pearmain			

The main disadvantage of the very protracted blossoming season lies therein, that the tree during a very vulnerable period may be exposed to adverse and fluctuating temperature and moisture conditions for a protracted period and that this often adversely affects the set of the crop. Moreover a long bloom period gives rise to crops of fruit irregular in size and differing in internal composition. Consequently fruits of considerable size will be found on trees which are still blooming, and this irregularity in setting is the bug-bear of the fruit grower and of the entomologist. It is the direct cause of heavy losses from Codling moth in apples and pears, and of bud-mite in pear buds and of imperfect control of some of our fungus diseases which require delayed dormant or early spring sprays at a specific stage of fruit or bud development. As too frequent spraying is impracticable, it follows that sprays cannot always be timed as desired and this results in imperfect pest control.

Irregular and protracted growth initiation in spring is followed by a somewhat protracted cessation of growth in the autumn, and this forms the crux of the delayed foliation problem.

Deciduous fruit trees require a period of rest and low temperatures at the approach of winter finally causing a shedding of the leaves and a practical cessation of tree activity. The rest requirements of the trees as regards the length of the dormancy period before it is ready to resume growth in spring will vary according to variety, but in a general way the almond and the Japanese plum require a shorter rest than many varieties of pears and most varieties of apples. If the growing season at any place is long, providing a dormant period too short for a particular variety, that variety will exhibit the familiar symptoms of delayed foliation with its attendant ill effects upon fruit production. The early blossoming varieties mentioned in Table I require only a short period of dormancy, while the late bloomers need longer and colder winters for normal development. Only these late flowering varieties exhibit delayed foliation symptoms and these are the varieties which respond to remedial measures in the form of oil emulsion sprays in early spring.

The South African growing season is very long, leaving only a short interval during which temperatures are sufficiently low to give deciduous fruit trees the rest they require. This is the difficulty in growing varieties such as Gaviota and d'Agen among plums; Early Alexander, High's Early Canada, Duke of York and Peregrine and most canning varieties among peaches; Bon Chrétien, Beurré Hardy and Glou Morceau among pears; and Rome Beauty, Chemimuri and Rokewood among apples, all of these requiring longer periods of dormancy than obtained at Stellenbosch and many other parts of the Western Province. Here the period of dormancy lasts approximately 90 days compared with a dormancy period of 150 days or longer in Latitude 40 in the Northern Hemisphere where these varieties attain a high degree of perfection. The brevity of the period of dormancy then is a major factor which adversely affects the growth and fruiting of many fruit tree varieties at the Cape.

Summarizing briefly, South Africa is so situated geographically that the period of dormancy is too short for many trees, and associated with this short period are high winter temperatures which are deleterious both as regards quantity and quality of the fruit crop. The critical mean maximum temperature for the four winter months, May, June, July and August, appears to be approximately 64·5° F. at Stellenbosch. If temperatures go above this figure, either the quantity or quality of the crop of susceptible varieties may be expected to suffer.

High winter temperatures are generally associated with excessive radiation and low atmospheric humidity, and while all these factors adversely affect the tree, air temperatures appear to be a good criterion of the amount of damage which may be expected.

Since 1917, and particularly from 1925 onwards, winters have been very mild and it is suggested that this is one of the biggest factors responsible for the complaints regarding South African fruit from overseas.

This investigation emphasizes the importance of the environment and the necessity for the fruit grower to have a clear picture of his own environmental conditions and of the inherent characteristics of the trees which he wishes to grow. Each fruit has special requirements regarding atmospheric conditions and the temperatures which prevail especially during the winter months, and these climatic requirements must be met, if the best results are to be obtained. Growers have been too prone in the past to select varieties according to the highest prices paid per tray of fruit on overseas markets, and insufficient attention has been paid to the adaptability of these varieties to local environment.

This investigation also emphasizes the necessity for immediately top-working poor bearers to more profitable varieties and the attention of fruit growers is drawn to the improved modern methods of tree-grafting which have been described and are being recommended by the Stellenbosch-Elsenburg College of Agriculture.

Efforts have been made to treat trees so that they will overcome the effects of mild winters, and as the experiments cover a period of several years, spraying susceptible varieties of apples, pears, Japanese plums and prunes with certain oil emulsions at elevations up to 2,000 feet in the Western Cape Province and South-Western Districts is recommended. These sprays, if properly applied will improve not only the quantity and quality of the fruit, but will have a beneficial effect upon the general health and vigour of the tree.

The Imperial Bureau of Fruit Production has been responsible for the proof reading of this paper in order that its publication may not be unduly delayed.

(*Received* 13/4/36.)

SOME PHYSIOLOGICAL EFFECTS OF OIL SPRAYS UPON DECIDUOUS FRUIT TREES

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INTRODUCTION.

Deciduous fruit trees pass through a resting stage every year. According to Chandler (4) and other workers, this rest period is broken by cold temperatures in winter, and the tree resumes normal growth in spring only after it has been subject to low temperatures during the winter months. If the winter climate is too mild to break the rest, a protracted blossoming and foliation occur, causing the tree to set a small yield of fruit of inferior quality. Since the normal cycle of growth is disturbed, the general condition of the tree is characterized by a lack of vigour and a paucity of foliage.

This phenomenon of "delayed foliation" is a serious problem to fruit growers in the coastal and low-lying sections of South Africa. In the Western Cape Province, the main centre of deciduous fruit production, it is one of the major problems of the fruit industry (18).

It has long been known that the rest period of trees and plants can be broken by artificial means. It is possible, for instance, to break the rest by the use of anaesthetics such as chloroform or ether. According to Chandler (4) and others (4, 12) the following methods have proved effective: treatment with acetylene gas, immersion in solutions of potassium nitrate, sodium nitrate, hydrogen cyanide, hydrogen peroxide, by exposing tissue to Röntgen rays (21, 22); immersion in weak solutions of potassium chloride, copper sulphate, hydrochloric acid, oxalic acid, acetic acid (12, 13 and 14); continuous exposure to electric light (10); exposure to smoke of tobacco, immersion in water at 30° C.-35° C. (16, 17).

Colville (6) states that the breaking of the rest, either by natural or artificial means, is a purely localized effect. He was able to break the rest of individual buds by practices such as ringbarking, rubbing the bark near the bud, etc.

Various sprays, especially oil sprays, have been known to break the rest period. According to Chandler (5) a dormant spray of nitrate of soda may have the effect of breaking the rest. Mally (15) obtained a more even blossoming and foliation on apples, pears and prunes with dormant applications of certain oil sprays (especially raw linseed oil and seal oil). The effects were less striking on peaches and apricots. He concludes that raw linseed oil tends to normalize the tree whereas the mineral oils, which proved less effective, had more a forcing effect without eliminating the irregularity in the tree. The stimulating effects of mineral oils on the blossoming and foliation of fruit trees have frequently been observed by workers in America. Burroughs (3) found that a dormant spray of Diamond paraffin oil hastened the blossoming of cherries in Missouri by three to six days, but he noticed no effects on other trees.

Ballard and Volck (1) working on apple Powdery Mildrew in California report that a dormant application of an oil spray prepared from crude oil, lye and fish oil soap stimulated a vigorous early growth of foliage.

Dutton (8, 9) found that soluble sulphur, nitrate of soda and also two winter oils (Scalecide and Punoco spray oil) had the effect of breaking the rest period of pears and peaches, but that lime sulphur showed no such influence. He is of opinion that oil sprays can hasten or delay blossoming, depending on the time of application and general environmental conditions.

Herbert (11) claims that some growers in California obtain larger crops and better sized fruit on pears, prunes and apricots by spraying with miscible oils ; the trees blossom from five to twenty days earlier and also start growth earlier.

De Ong (7) in California sprayed prune trees with a 6 per cent. oil emulsion at fortnightly intervals during the four months preceding the blossoming period of the trees (November 15th-March 15th). He found that the November treatment (i.e. early winter) delayed blossoming whereas the December spray showed no effect ; spraying in January definitely caused the trees to blossom earlier, but the blossoming period was delayed by a later spray in February.

Borden (2), also working in California, states that the greatest stimulation on blossoming occurs when applications of oil are made early in January. The stimulation appeared to be more apparent at the time of the unfolding of the bud than at full bloom time. He noted the greatest stimulation with an oil of seventy seconds viscosity and about 67 per cent. unsulphonated residue.

From this brief résumé of literature it can be concluded that oil sprays may under certain conditions have the effect of breaking the rest period of deciduous fruit trees. Most overseas workers have, however, not attached much significance to these physiological effects of oil sprays. But in South Africa, largely due to Mally's (15) work, many growers in the Western Cape Province have made a regular practice of spraying their trees (especially apples, pears and prunes) with raw linseed oil, seal oil, whale oil or with the commercial mineral oil sprays with the object of getting a more even blossoming and better crops. But the results often vary and growers are still very much in the dark as to the actual effects of oil treatment on blossoming, fruit production and on the growth of the tree in general and as to the extent that varieties differ in this respect ; moreover, there are no data available regarding the best time to spray.

EXPERIMENTAL PROCEDURE.

To obtain more specific information on these points, spraying experiments with raw linseed oil emulsion* (5 per cent.) were carried out at the Experimental Farm, Stellenbosch, during the years 1933, 1934 and 1935. Although it was known that other vegetable and animal oils such as whale oil and seal oil produced somewhat similar effects on the tree, raw linseed oil was chosen as being fairly representative of this class of oil. In the 1935 season comparative tests were, however, also made with seal oil* and with two proprietary mineral oil emulsions: Kleenup and Pestridol. These proprietary mineral oil emulsions —referred to hereafter as mineral oil Kp. and Pl. respectively—contain semi-refined mineral oils of the lubricating oil type. The total oil content approximates to 80 per cent. so that a 5 per cent. emulsion will contain about 4 per cent. of oil. Since the idea had become prevalent amongst growers that mineral oil sprays were not so effective in stimulating blossoming as glyceride oils such as raw linseed oil, it was decided to study the following aspects of the problem, viz. :

(a) The stimulation effects of oil sprays on fruit and leaf buds and the practical value of these effects in so far as fruit production is concerned.
(b) The best time to spray.
(c) Varietal differences in regard to response to oil treatment.

Since the effect of oil sprays is purely localized, the different treatments were mostly applied to individual branches on each tree. For each variety a minimum of two trees was used and the results were worked out separately for each tree. In this way the experimental error arising from variations between different trees was largely eliminated. For each treatment at least four large branches were used. The spray was applied with a small painter's brush. Spraying turned out to be impracticable since it proved quite impossible to prevent the spray mist from reaching other parts of the tree. A 5 per cent. oil emulsion was used throughout the experiment and was applied at three to four different stages during late winter. When blossoming was well advanced the test branches were inspected and data obtained by noting down the stage of development of each fruit bud and leaf bud. The varieties used in the experiment were the following:

Pears: Bon Chrétien and Beurré Hardy ; *Apples:* White Winter Pearmain. Supplementary data in 1935 were also obtained on Ohenimuri apple trees at Elgin, C.P. and Stellenbosch. In the variety tests, sixteen pear varieties were used.

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* Casein-ammonia stock emulsion kindly supplied by Cape Explosive Works, Somerset West.

A. EFFECT OF OIL SPRAYS ON BLOSSOMING.

Experimental Results.

Bon Chrétien: In the first year (1933) the raw linseed oil spray was applied on the following dates: August 4th, 15th, 29th and September 11th. All the branches were inspected on the same date, September 27th, and the fruit buds grouped in the following classes:

Stage I. Buds dormant.
,, II. Swelling—Bursting Stage (Fig. 1).
,, III. Cluster—Pink Stage (Figs. 2 and 3).
,, IV. Flowers open (Full Bloom).

Two further classes were added in later years:

Stage V. Calyx or Petal Fall.
,, VI. Fruit Set.

Table I.

Effect of Raw Linseed Oil Emulsion (R.L.) on the Blossoming of Bon Chrétien (1933).

Treatment.	No. Buds inspected.	Stage I. %	Stage II. %	Stage III. %	Stage IV. %
Tree No. 1.					
Untreated	127	5	79	16	0
R.L. Aug. 4th	23	0	35	65	0
R.L. Aug. 15th	36	0	30	39	31
R.L. Aug. 29th	39	0	23	72	5
R.L. Sept. 11th	24	0	87	13	0
Tree No. 2.					
Untreated	56	4	54	40	2
R.L. Aug. 4th	11	9	55	27	9
R.L. Aug. 15th	18	0	50	33	17
R.L. Aug. 29th	28	0	36	64	0
R.L. Sept. 11th	26	0	58	42	0
Tree No. 3.					
R.L. Aug. 15th	7	0	0	57	43
R.L. Aug. 29th	16	0	57	31	12
R.L. Sept. 11th	12	0	75	25	0

The results clearly show that the spray treatment on August 15th considerably advanced the blooming period of Bon Chrétien, and that the stimulation of this treatment was greater than with any of the others. Of the three other spraying dates, August 29th showed the most effect on blossoming, followed by August 4th, but the September 11th treatment showed no advantage over the control.

It should be mentioned here that the 1933 season proved to be exceptionally favourable for normal blossoming and foliation of fruit trees at Stellenbosch and with most varieties "delayed foliation" was not much in evidence. Temperature records at Stellenbosch show the 1933 winter to be the coldest since 1926. Unsprayed Bon Chrétiens blossomed fairly normally, yet even under these conditions oil treatment quite definitely stimulated the opening of fruit buds.

Bon Chrétien Results in 1934.

In contrast to the previous year, the 1934 season turned out to be distinctly abnormal and proved singularly conducive to "delayed foliation". A 5 per cent. raw linseed oil emulsion was again used and applied on the following dates: July 25th, August 17th, September 3rd. The trees were inspected on October 2nd, and data obtained in the same way as in 1933, although an additional class—No. V. Calyx Stage—was now noted.

Table II.

Effect of Raw Linseed Oil Emulsion (R.L.) on the Blossoming of Bon Chrétien (1934).

Treatment.	Total No. Buds.	Stage I. %	Stage II. %	Stage III %	Stage IV. %	Stage V. %
Tree No. 1.						
Untreated ..	37	51	35	14	0	0
R.L. July 26th ..	20	40	20	10	30	0
R.L. Aug. 17th ..	32	3	0	3	63	31
R.L. Sept. 3rd ..	36	0	0	50	50	0
Tree No. 2.						
Untreated ..	44	48	39	7	6	0
R.L. July 26th ..	30	20	17	23	40	0
R.L. Aug. 17th ..	35	8	11	6	51	24
R.L. Sept. 3rd ..	49	2	10	43	45	0

All three treatments had the effect of advancing the blossoming period of Bon Chrétien, but as in 1933, the mid-August spray was far more effective than any of the others.

The September spray, although not hastening the blossoming to the same extent as R.L. August 17th, gave more even blossoming. It is interesting to note in the above Table the high percentage of dormant buds on the unsprayed branches and on the branches sprayed on July 26th in contrast to the high percentage of buds in Stages IV and V for the oil treatment on August 17th.

It is also clear that the stimulating effect was much more pronounced in 1934 than in the previous year.

Bon Chrétien Results in 1935.

In this season, in addition to raw linseed oil emulsion (5 per cent.), the proprietary mineral oil emulsion (Kp., 5 per cent.) was used. Both oil sprays were applied on the following dates: August 6th, 17th and 30th; the trees were inspected at a later stage in spring than in previous years (October 28th), and a still later class—Stage VI. Fruit Set—was added to the other five stages.

Table III.

Effect of Raw Linseed Oil Emulsion (R.L.) on the Blossoming of Bon Chrétien (1935).

Treatment.	Total No. Buds.	Stage I. %	Stage II. %	Stage III. %	Stage IV. %	Stage V. %	Stage VI. %
Tree A.							
Untreated ..	87	46	0	1	9	36	8
R.L. Aug. 6th	78	47	0	0	0	15	38
R.L. Aug. 17th	105	29	0	0	0	15	56
R.L. Aug. 30th	68	27	0	0	0	70	3
Tree B.							
Check ..	119	45	0	1	3	28	23
R.L. Aug. 6th	77	33	0	0	0	8	59
R.L. Aug. 17th	112	28	0	0	0	14	58
R.L. Aug. 30th	63	28	0	0	0	35	37

Nearly half of the fruit buds of the unsprayed branches were either dead or still dormant; the remaining buds gave a long extended blooming period.

The spray treatment on August 6th showed very little difference from the control in the percentage of dormant or dead buds, but it produced an earlier and more even bloom. With the two later treatments fewer buds remained dormant. The mid-August treatment resulted in an early and fairly uniform blossoming season.

The branches treated on August 30th blossomed remarkably well and evenly, although the blossoms did not come out much earlier than on the check branches.

The results obtained with the mineral oil (Kp.) 5 per cent. emulsion on Bon Chrétien are given in Table IV.

The data show more or less the same tendencies as Table III, although the percentages of dormant or dead buds for the treatments on August 6th and 17th on Tree C appears to be unusually high. Summarizing the results for Bon Chrétien for the three successive seasons, 1933, 1934 and 1935, it seems quite evident that an oil spray promotes a larger, earlier and more even bloom, but that these effects are largely dependent on the time of spraying. Mid-August proved to be the most effective spraying date, followed by sprays given at the end of August. The latter usually gave a remarkably even bloom.

Data on the effects of raw linseed oil on blossoming were also obtained for the Beurré Hardy variety.

Table IV.

Effect of Mineral Oil Emulsion (Kp.) on the Blossoming of Bon Chrétien (1935).

Treatment.	Total No. Buds.	Stage I. %	Stage II. %	Stage III. %	Stage IV. %	Stage V. %	Stage VI. %
Tree C.							
Untreated	103	33	0	8	3	44	12
Kp. Aug. 6th	64	47	0	2	2	26	23
Kp. Aug. 17th	68	40	0	0	1	25	34
Kp. Aug. 30th	74	12	0	0	0	77	11
Tree D.							
Untreated	164	48	0	12	9	28	3
Kp. Aug. 6th	105	36	0	4	2	34	24
Kp. Aug. 17th	98	29	0	0	1	27	43
Kp. Aug. 30th	81	33	0	0	6	57	4

Beurré Hardy : In the first season (1933) tests were made on two trees both of which showed more or less the same response to oil treatment.

Unfortunately the trees were in an off year and had produced very few fruit buds the previous summer. Hence the number of fruit buds inspected was rather low and the results for the two trees are thus dealt with together in the following Table. The inspection was made on October 6th, 1933, and October 3rd, 1934.

Table V.

Effect of Raw Linseed Oil (R.L.) on the Blossoming of Beurré Hardy (1933).

Treatment.	Total No. Buds.	Stage I. %	Stage II. %	Stage III. %	Stage IV. %	Stage V. %
Check	25	0	28	40	32	0
R.L. Aug. 4th	8	0	75	25	0	0
R.L. Aug. 15th	14	0	14	0	57	29
R.L. Aug. 29th	15	0	0	20	13	67
R.L. Sept. 11th	26	0	11	31	58	0

Each of the spray treatments on August 15th and 29th had the effect of causing an earlier blossoming, the late August spray stimulating the fruit buds somewhat more than the mid-August treatment.

Regarding the early August spray, it would not be fair to draw any definite conclusions from the data as the number of fruit buds in this treatment is exceptionally low.

BEURRÉ HARDY RESULTS (1934).

TABLE VI.

Effect of Raw Linseed Oil (R.L.) on Blossoming: Beurré Hardy (1934).

Treatment.	No. Buds inspected.	Stage I. %	Stage II. %	Stage III. %	Stage IV. %	Stage V. %
Tree No. 1.						
Untreated ..	75	11	31	57	1	0
R.L. July 26th ..	48	8	42	33	17	0
R.L. Aug. 17th ..	69	1	6	33	57	3
R.L. Sept. 3rd ..	50	4	50	44	2	0
Tree No. 2.						
Untreated ..	52	46	40	14	0	0
R.L. July 26th ..	43	21	51	26	2	0
R.L. Aug. 17th ..	18	6	0	78	16	0
R.L. Sept. 3rd ..	34	12	12	42	14	0

All three treatments showed good effect this year. Blossoming was most advanced with the August 17th spray. It was more advanced than with the later spray (September 3rd) which proved so effective the previous year (on August 29th).

OIL SPRAY EFFECTS ON APPLE TREES.

The following are the results obtained with the White Winter Pearmain apple for the years 1933 and 1934. The same stages were used as in the case of pears. The inspection was made on October 11th.

TABLE VII.

Effect of Raw Linseed Oil on Blossoming: White Winter Pearmain (1933).

Treatment.	No. Buds inspected.	Stage I. %	Stage II. %	Stage III. %	Stage IV. %	Stage V. %
Tree No. 1.						
Untreated ..	35	3	20	51	23	3
R.L. Aug. 15th ..	42	0	5	36	26	33
R.L. Aug. 31st ..	48	0	6	42	38	14
R.L. Sept. 13th ..	40	0	20	65	10	5
Tree No. 2.						
Untreated ..	30	0	7	53	27	13
R.L. Aug. 15th ..	20	0	0	10	30	60
R.L. Aug. 31st ..	40	0	2	13	32	53
R.L. Sept. 13th ..	36	0	5	42	25	28

The most advanced blossoming occurred where the spray was applied on August 15th, closely followed by the treatment at the end of August; oil applications on September 13th appeared to have no or very little effect on blossoming. No early August spray was applied.

The 1934 season proved to be an off year for White Winter Pearmain and fruit buds were somewhat scarce on both trees. The number of buds which were treated is rather too low to allow for a fair comparison. However the data, collected on October 3rd, appear to indicate that the blossoming of White Winter Pearmain was also stimulated by oil treatment in this season.

TABLE VIII.

Effect of Raw Linseed Oil (R.L.) on Blossoming: White Winter Pearmain (1934).

Treatment.	No. Buds inspected.	Stage I. %	Stage II. %	Stage III. %	Stage IV. %	Stage V. %
Untreated	20	50	25	20	5	0
R.L. Aug. 17th ..	6	17	17	0	0	66
R.L. Sept. 3rd ..	13	15	0	8	38	39

Some striking effects of oil sprays on blossoming were obtained in 1935 in a series of field tests on the Ohenimuri apple in the Elgin and Stellenbosch districts. These tests were originally meant to serve for demonstration purposes, but the oil effects showed up so convincingly, that it was decided to take observation records during the blooming season. A brief summary of the records made on October 16th and 18th respectively are given in Tables IX and X below.

TABLE IX.

Notes on the Effects of Oil Sprays on the Blossoming of Ohenimuri at H. W. Blackburn's Farm, Elgin, C.P.

No. of Trees per Plot: 12.

Treatment and Date of Spraying.	Stage of Blossoming.	Condition of Blossoming.
Unsprayed	First bloom.	Very irregular; majority of fruit buds still dormant. [See Fig. 4.]
Seal Oil (5%) (1st week August)	Full bloom.	Uneven.
Mineral Oil (Kp.) (5%) (1st week August)	Full bloom.	Uneven.
Seal Oil (5%) (3rd week August)	Full bloom.	Even and regular blossoming.
Mineral Oil (Kp.) (5%) (3rd week August) ..	Full bloom.	Even and regular blossoming. [See Fig. 5.]
Seal Oil (5%) (end August)	First bloom.	Remarkably even.
Mineral Oil (Kp.) (5%) (end August) ..	First bloom.	Remarkably even.

TABLE X.

Notes on the Effects of Oil Sprays on the Blossoming of Ohenimuri at Farm "Groot Salze", Vlottenberg, Dist. Stellenbosch.

No. of Trees per Plot: 3.

Treatment and Date of Spraying.	Stage of Blossoming.	Condition of Blossoming.
Unsprayed	Pre-blossom stage.	Very irregular; majority of fruit buds still dormant.
Raw Linseed Oil (5%) (1st week August)	First bloom; Slightly in advance of check.	Very uneven.
Mineral Oil (Kp.) (5%) (1st week August)	Full bloom.	Uneven.
Raw Linseed Oil (5%) (3rd week August) ..	Not yet quite in full bloom.	Uneven, but not to the same extent as the earlier sprays.
Seal Oil (5%) (3rd week August) ..	Not yet quite in full bloom.	Uneven, but not to the same extent as the earlier spray.
Mineral Oil (Kp.) (5%) (3rd week August) ..	Well advanced in full bloom.	Fairly even.
Mineral Oil (Pl.) (5%) (1st week September) ..	Well advanced in full bloom.	Fairly even.
Raw Linseed Oil (5%) .. (1st week September) ..	Past first bloom, but not yet full bloom.	Blossoming very even.

At Elgin all the sprayed trees were well in advance of those not sprayed. Mineral oil (Kp.) in early August gave an earlier bloom than seal oil on the corresponding date, but in both cases the blossoming came out very unevenly. On subsequent spraying dates there appeared to be no significant difference between the two kinds of oils. Spraying at the end of August did not result in an earlier bloom, but showed promise of a remarkably regular blossoming season; most of the fruit buds were in the cluster and pink stages. A further point of interest regarding this late August treatment was that the leaf buds were sprouting practically simultaneously with the fruit buds. Spraying in the third week of August resulted in a good combination of earliness and evenness of bloom.

At Vlottenberg in the Stellenbosch district, seal oil and raw linseed oil appeared to be rather inferior in stimulation effects to the mineral oils, especially when applied early in August. Raw linseed oil in the beginning of September, however, showed good promise.

Spraying tests of a similar nature to the above were also made on the Bon Chrétien variety at the University Farm, Stellenbosch. The various oils did not show any striking differences on this variety; if anything, raw linseed oil and seal oil proved somewhat more effective than the two mineral oils (Kp. and Pl.). The importance of time of spraying was again brought to light; the earlier the spray was applied in August, the more protracted the blossoming appeared to be. Spraying at the end of August gave a very regular blossoming season; the entire bloom came out, as it were, in a flush, but blossoming did not commence as early as with the mid-August treatment.

B. THE EFFECT OF OIL SPRAYS ON VEGETATIVE GROWTH.

To determine the effects of oil treatment on leaf bud development, a similar method of recording was followed as with the fruit buds. All leaf buds on one year old wood were inspected on the same date and classified according to stage of development.

The stages were as follows:

Stage I. Dormant.
,, II. Swelling—Bursting Stage (Fig. 6).
,, III. Leaf Cluster unfolding, but no full-sized leaves present yet (Fig. 7).
,, IV. Growth further advanced. (Mature leaves present and shoot or spur growth taking place.)

TABLE XI.

Effect of Raw Linseed Oil (R.L.) on the Opening of Leaf Buds: Bon Chrétien (September 28th) (1933).

Treatment.	No. Buds inspected.	Stage I. %	Stage II. %	Stage III. %	Stage IV. %
Tree No. 1.					
Untreated	162	97	3	0	0
R.L. Aug. 4th	29	52	48	0	0
R.L. Aug. 15th	97	75	24	1	0
R.L. Aug. 29th	42	55	39	6	0
R.L. Sept. 11th	47	81	19	0	0
Tree No. 2.					
Untreated	82	100	0	0	0
R.L. Aug. 4th	66	100	0	0	0
R.L. Aug. 15th	88	44	38	16	2
R.L. Aug. 29th	52	48	46	6	0
R.L. Sept. 11th	45	82	18	0	0

Practically all the leaf buds on the check shoots are still dormant, whereas the oil treatments, excepting the early August spray on Tree No. 2, had a stimulating effect on the opening of the buds. On Tree No. 1 the spray treatment on August 29th showed the greatest effect but on Tree No. 2 the mid-August treatment proved equally or even more effective.

TABLE XII.

Effect of Raw Linseed Oil (R.L.) on the Opening of Leaf Buds: Bon Chrétien (October 2nd) (1934).

Treatment.	No. Buds inspected.	Stage I. %	Stage II. %	Stage III. %	Stage IV. %
Tree No. 1.					
Untreated	142	93	6	1	0
R.L. July 26th	48	98	0	2	0
R.L. Aug. 17th	167	49	16	13	22
R.L. Sept. 1st	207	44	35	9	12
Tree No. 2.					
Untreated	294	95	5	0	0
R.L. July 26th	103	97	3	0	0
R.L. Aug. 17th	151	70	14	6	10
R.L. Sept. 1st	244	69	20	6	5

The early spray (R.L. July 26th) failed to show much response, but the other two treatments (i.e. mid-August and end-August) showed up well against the control.

It should be mentioned here that, for both the seasons 1933 and 1934, the records were taken at the very beginning of the growing season and for that reason the data may perhaps not reflect the true position later in the season. A large proportion of the buds, that were still dormant at the time of inspection, would probably have come out later. However, the main point brought out by the results in Tables XI and XII is that the oiled branches, especially those treated in the latter half of August, produced an earlier vegetative growth and a larger initial leaf surface than the untreated branches.

The results which were observed on October 28th for 1935 are given in Tables XIII and XIV.

TABLE XIII.

Effect of Raw Linseed Oil (R.L.) on the Opening of Leaf Buds: Bon Chrétien (1935).

Treatment.	No. Buds inspected.	Stage I. %	Stage II. %	Stage III. %	Stage IV. %
Tree No. 1.					
Untreated	288	44	35	15	6
R.L. Aug. 6th	186	63	17	11	9
R.L. Aug. 17th	338	48	17	10	25
R.L. Aug. 30th	191	21	7	22	50
Tree No. 2.					
Untreated	251	46	29	14	11
R.L. Aug. 6th	157	54	13	9	24
R.L. Aug. 17th	209	38	13	12	37
R.L. Aug. 30th	159	18	13	15	54

TABLE XIV.

Effect of Mineral Oil (*Kp.*) *on the Opening of Leaf Buds : Bon Chrétien* (1935).

Treatment.	No. Buds inspected.	Stage I. %	Stage II. %	Stage III. %	Stage IV. %
Tree No. 3.					
Untreated	331	69	23	5	3
Kp. Aug. 6th	95	73	12	6	9
Kp. Aug. 17th	190	37	8	15	41
Kp. Aug. 30th	126	24	6	24	46
Tree No. 4.					
Untreated	—	69	25	5	1
Kp. Aug. 6th	—	66	21	7	6
Kp. Aug. 17th	—	32	16	23	29
Kp. Aug. 30th	—	35	16	17	32

Here again the early spray (August 6th) had practically no stimulating effect on the leaf buds. On three of the four trees it even appeared to cause more of the buds to remain dormant. The later in August the spray was applied, the more effective it became. For both raw linseed oil and the mineral oil (Kp.), August 30th proved to be the best spraying date. Not only did this treatment considerably advance the growing season, but it also caused a large proportion of the buds to open and to develop into spurs or shoots. Data on the effect of raw linseed oil treatment on leaf bud development for the Beurré Hardy and White Winter Pearmain varieties are given below:

TABLE XV.

Effect of Raw Linseed Oil Emulsion (5 *per cent.*) (*R.L.*) *on the Opening of Leaf Buds of Beurré Hardy* (*October* 6*th*) (1933).

Treatment.	Total No. of Leaf Buds inspected.	Stage I. %	Stage II. %	Stage III. %	Stage IV. %
Tree No. 1.					
Untreated	185	25	30	41	4
R.L. Aug. 4th	28	32	25	36	7
R.L. Aug. 15th	67	13	17	31	39
R.L. Aug. 29th	91	20	15	27	38
R.L. Sept. 11th	109	16	33	19	32
Tree No. 2.					
Untreated	95	22	29	38	11
R.L. Aug. 4th	49	49	32	19	0
R.L. Aug. 15th	39	18	0	13	69
R.L. Aug. 29th	76	9	6	12	73
R.L. Sept. 11th	88	27	24	29	20

It will be seen that growth was stimulated on all the oiled branches excepting those sprayed early in August.

Growth was most advanced with the August 15th and August 29th treatments, although the later application on September 11th also showed quite good stimulation.

TABLE XVI.

Effect of Raw Linseed Oil Emulsion (5 *per cent.*) (*R.L.*) *on the Opening of Leaf Buds of Beurré Hardy* (*October 3rd*) (1934).

Treatment.	No. of Buds.	Stage I. %	Stage II. %	Stage III. %	Stage IV. %
Tree No. 1.					
Untreated	127	64	36	0	0
R.L. July 26th	20	65	25	10	0
R.L. Aug. 17th	67	10	22	63	5
R.L. Sept. 3rd	64	20	80	0	0
Tree No. 2.					
Untreated	105	68	29	2	1
R.L. July 26th	48	73	19	8	0
R.L. Aug. 17th	66	9	15	41	35
R.L. Sept. 3rd	48	29	63	2	6

Here again the early spray showed very little or no superiority over check. The greatest effect is noticeable with the mid-August treatment. The later spray on September 3rd (corresponding to the August 29th spray of the previous year), though not stimulating as early a growth, caused the buds to open very evenly.

TABLE XVII.

Effect of Raw Linseed Oil Emulsion (5 *per cent.*) (*R.L.*) *on Leaf Bud Development: White Winter Pearmain* (*October* 11*th*) (1933).

Treatment.	No. of Buds.	Stage I. %	Stage II. %	Stage III. %	Stage IV. %
Tree No. 1.					
Untreated	203	28	36	36	0
R.L. Aug. 15th	92	22	5	51	22
R.L. Aug. 31st	71	21	17	49	13
R.L. Sept. 13th	98	25	16	58	1
Tree No. 2.					
Untreated	88	36	20	33	1
R.L. Aug. 15th	82	23	15	40	22
R.L. Aug. 31st	56	29	16	48	7
R.L. Sept. 13th	67	36	22	36	1

August 15th is indicated as the best spraying date, although there is also a notable stimulation apparent with the late August treatment (August 31st). Spraying late in September (September 13th) did not prove effective.

TABLE XVIII.

Effect of Raw Linseed Oil Emulsion (5 *per cent.*) *on Leaf Bud Development: White Winter Pearmain* (*October 3rd*) (1934).

Treatment.	No. of Buds.	Stage I. %	Stage II. %	Stage III. %	Stage IV. %
Untreated	281	67	24	9	0
R.L. Aug. 17th	169	30	20	23	27
R.L. Sept. 3rd	165	25	14	24	27

Only two spraying dates were compared and there does not appear to be any appreciable difference in effect between the two dates. Both treatments, however, caused a stimulation of the leaf buds.

From the above data it can be concluded that for the varieties Bon Chrétien, Beurré Hardy and White Winter Pearmain, the leaf buds are most responsive to oil treatment from the middle to the end of August. Spraying early in August usually gave negative results. The end of August proved throughout a very suitable time for spraying.

Furthermore, the results show that an oil spray has the effect of causing more leaf buds to open and to develop, thus producing a larger leaf surface and an increased vigour in the tree. Moreover it stimulates an earlier vegetative growth, thus effecting a more normal growth cycle.

Further data in support of this statement were obtained in a spraying test with Bon Chrétien during the 1935 season. A number of Bon Chrétien trees were half sprayed ; a canvas sheet drawn through the main branches and held in position, divided the tree into two equal portions. The one half of the tree was sprayed, the unsprayed half serving as control.

The leaf buds on ten one year old branches on either side of the tree were kept under observation during the growing season and the percentage of buds remaining dormant, the percentage forming spurs, and the percentage forming shoots, determined.

Furthermore, growth measurements of the young shoots were made at weekly intervals in order to obtain information on the respective lengths of growing season for the sprayed and unsprayed tree-halves. Fig. 8 shows a typical Bon Chrétien pear tree half sprayed and half unsprayed, photographed six weeks after the treatment.

It might be mentioned here that these trees are situated in an exposed orchard and that they showed rather severe symptoms of " delayed foliation ".

TABLE XIX.

Effect of Raw Linseed Oil Emulsion, 5 per cent. (August 21st), on the Development of Leaf Buds of Bon Chrétien trees, half sprayed.

Tree No.	Treatment.	No. of Buds inspected.	% Dormant at end growing season.	% Spurs.	% Shoots.	% Crop.
A.	Sprayed half (West side)	92	43	43	14	90
	Unsprayed half (East side)	95	82	7	11	10
B.	Sprayed half (East side)	100	53	29	18	80
	Unsprayed half (West side)	84	87	2	11	20

TABLE XX.

Effect of Mineral Oil (Pl.) Spray, 5 per cent. (August 21st), on the Development of Leaf Buds of Bon Chrétien trees, half sprayed.

Tree No.	Treatment.	No. of Buds inspected.	% Dormant at end growing season.	% Spurs.	% Shoots.	% Crop.
C.	Sprayed half (West side)	89	63	17	20	88
	Unsprayed half (East side)	103	86	6	8	12
D.	Sprayed half (East side)	104	40	44	16	70
	Unsprayed half (West side)	95	81	10	9	30

On all four trees the sprayed half produced a much larger proportion of spurs and also somewhat more young shoots than the unsprayed halves (see diagram). Of special note is the exceptionally high percentage of buds still dormant on the unsprayed tree-halves. The unsprayed branches all showed a typical appearance—a vigorous shoot or two at the tip of the branch and for the rest, except for an occasional spur, there was no bud development. On the other hand the sprayed branches showed a very much better spur development, thus furnishing a large potential bearing surface. The crop data also show a significant difference in favour of the spray treatments.

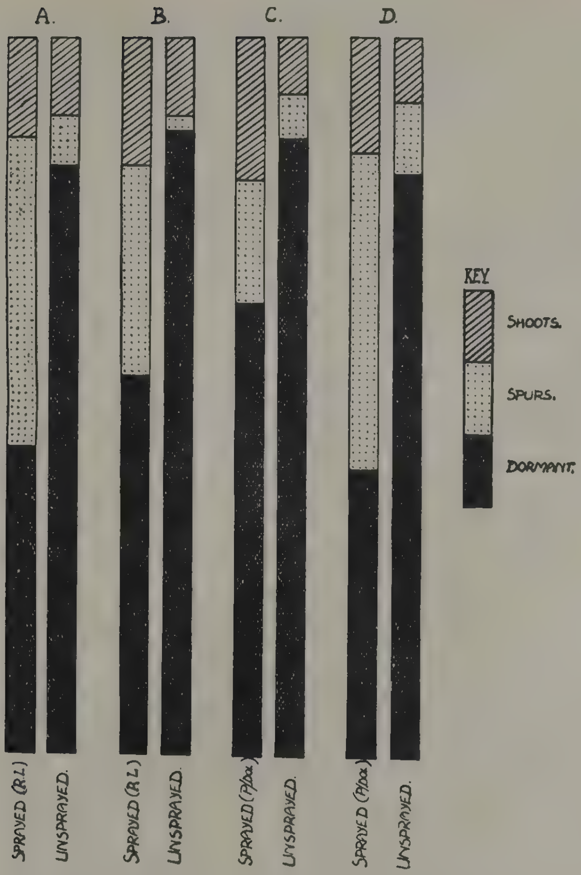


DIAGRAM SHOWING EFFECT OF OILS ON BUD, SPUR, AND SHOOT DEVELOPMENT OF BON CHRÉTIEN PEAR TREES.

TABLE XXI.

Effect of Raw Linseed Oil Emulsion, 5 per cent. (August 21st), on the Duration of the Vegetative Growing Season of Bon Chrétien.

Tree No.	Treatment.	Nov. 6th.	Nov. 14th.	Nov. 21st.	Nov. 28th.	Dec. 5th.	Dec. 12th.	Dec. 20th.	Jan. 3rd.
A.	Sprayed half (West side)	20	27	31	33	34	34	34	34
	Unsprayed half (East side)	15	24	31	33	35	36	38	40
B.	Sprayed half (East side)	19	30	37	40	41	42	42	42
	Unsprayed half (West side)	11	20	29	37	42	45	46	47

TABLE XXII.

Effect of Mineral Oil (Pl.) Spray, 5 per cent. (August 21st), on the Duration of Vegetative Growing Season of Bon Chrétien.

Tree No.	Treatment.	Average Shoot Length (cms.).							
		Nov. 6th.	Nov. 14th.	Nov. 21st.	Nov. 28th.	Dec. 5th.	Dec. 12th.	Dec. 20th.	Jan. 3rd.
C.	Sprayed half (West side)	19	29	35	40	42	44	44	44
	Unsprayed half (East side)	16	27	31	37	44	46	48	49
D.	Sprayed half (East side)	13	21	28	33	34	35	35	35
	Unsprayed half (West side)	14	25	32	40	44	46	47	47

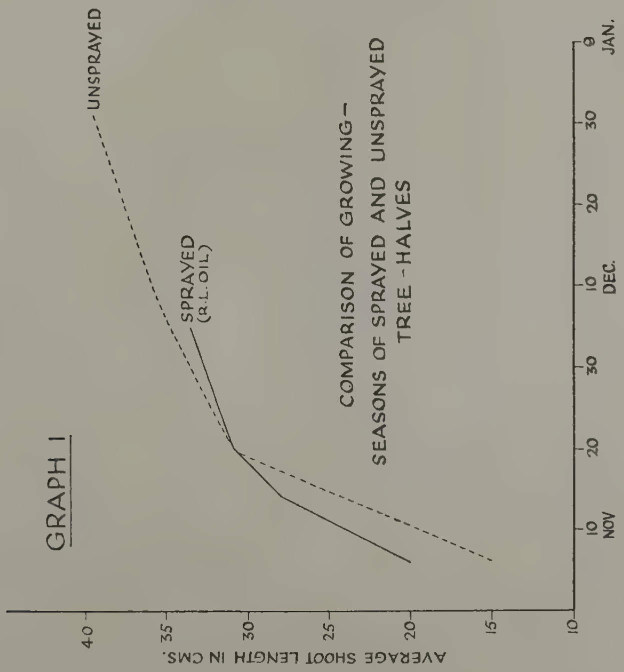
A clearer vision of the position will be obtained by studying Graphs I, II, III and IV. On November 6th shoot growth was generally more advanced on the sprayed than on the unsprayed tree-halves. But the sprayed branches ceased length-growth early in December whereas the unsprayed branches were still in active growth at the end of the month. It is interesting to note that the average shoot length on January 3rd is higher for unsprayed than for sprayed branches, showing that in the former cases a vigorous delayed growth took place.

C. EFFECT OF OIL SPRAYS ON YIELD.

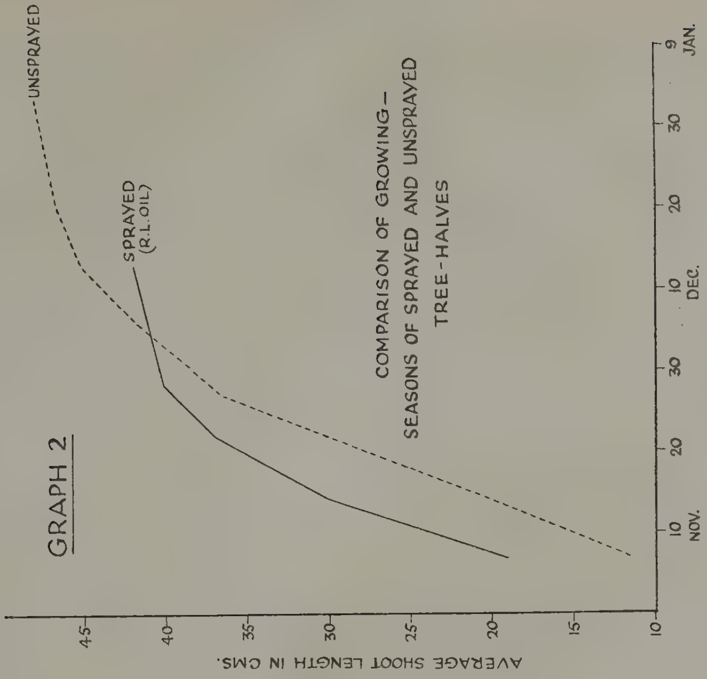
Hitherto the data have indicated the significance of oil sprays in so far as blossoming and vegetative growth are concerned ; but it may well be asked how the actual crop production of the tree would benefit hereby.

It is a well-known fact that the condition of " delayed foliation " results in low yields. And since an oil spray tends to counteract the ill-effects of " delayed foliation " it may also be expected to bring about a marked improvement in the crop. This is borne out by crop data for two successive years for the Bon Chrétien variety.

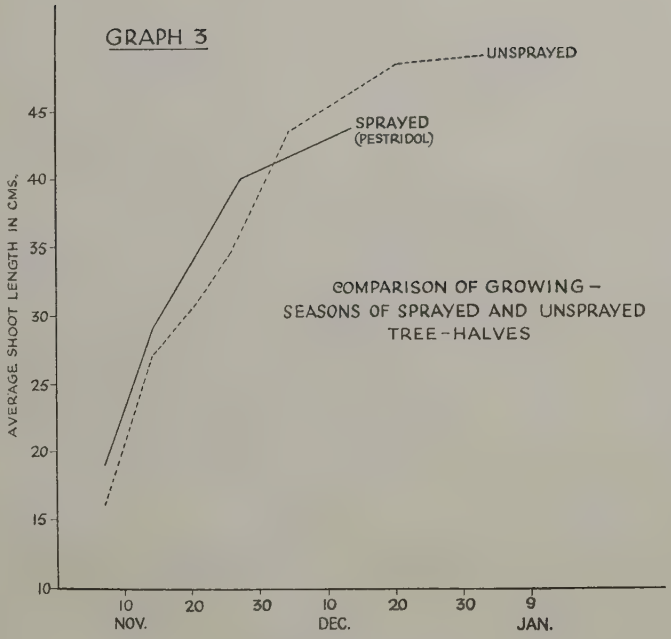
All the oil treatments gave a marked increase in yield over the controls. There also appears to be a correlation between the degree of stimulation of fruit buds, coupled with uniformity of bloom on the one hand, and the size of the crop on the other. In the 1934-35 season the spray on August 17th gave the earliest and most uniform bloom, closely followed by the later spray on September 3rd. In the following year the mid-August treatment again produced an early bloom, but it did not reach the uniformity of the later spray (August 31st). This latter treatment gave a remarkably short blossoming period during which time the conditions were very favourable for a good set. If reference is made to Tables XIX and XX, it will be seen that the stimulation effect of oil sprays on leaf buds resulted in more spurs and shoots being formed. It stands to



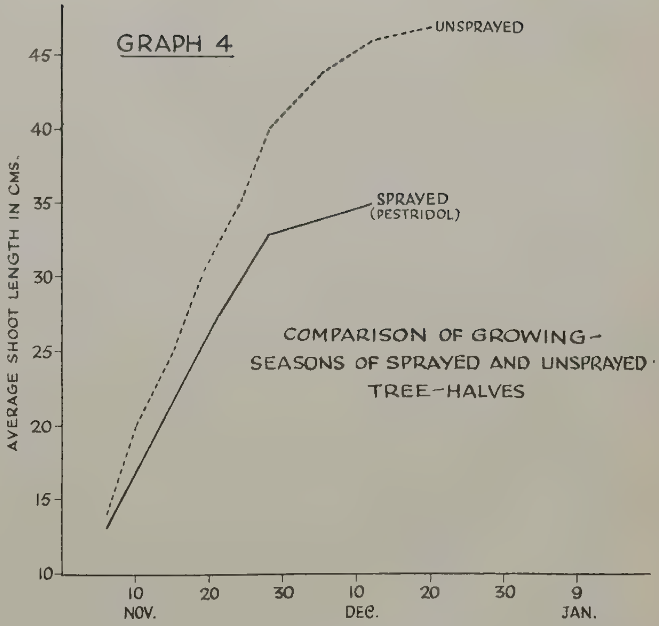
Graph 1.
Tree No. A (see Table XXI).



Graph 2.
Tree No. B (see Table XXI).



Graph 3.
Tree No. C (see Table XXII).



Graph 4.
Tree No. D (see Table XXII).

reason that this would inevitably lead to an increase in the bearing surface of the tree.

TABLE XXIII.

Crop data: Bon Chrétien Trees (1) *and* (2) (1934-35).

Treatment.	Total No. Fruit Buds.	No. of Fruit produced.	Average No. Fruit per Fruit Bud.	Increase in Crop.
Check	81	38	0·47	—
R.L. July 26th ..	52	58	1·1	134%
R.L. Aug. 17th ..	67	220	3·3	502%
R.L. Sept. 3rd ..	85	218	2·6	453%

Crop data: Bon Chrétien Trees (1) *and* (2) (1935-36).

Treatment.	Total No. Fruit Buds.	No. of Fruit produced.	Average No. Fruit per Fruit Bud.	Increase in Crop.
Check	206	28	0·14	—
R.L. Aug. 6th ..	155	67	0·43	207%
R.L. Aug. 17th ..	217	119	0·55	293%
R.L. Aug. 31st ..	131	97	0·74	428%

To obtain more specific data on these indirect effects of oil sprays on crop production, it was decided to calculate the relative number of fruit buds differentiated on sprayed and unsprayed branches of Bon Chrétien during the 1934-35 summer. To obtain comparable figures the number of fruit buds was determined per 100 cms. growth (a) on spurs, and (b) on one year old shoots.

TABLE XXIV.

Effect of Raw Linseed Oil Emulsion on the Formation of Fruit Buds on Spurs (Bon Chrétien, 1934-35).

	Unsprayed (8 branches).	Sprayed (Aug. 17th) (6 branches).
Tree No. 1.		
Total length of 2 year old and older wood	1,335 cms.	1,104 cms.
Total No. fruit buds (on spurs)	32	85
No. fruit buds per 100 cms. old wood	2·4	7·7

	Unsprayed (6 branches).	Sprayed (Aug. 17th) (5 branches).
Tree No. 2.		
Total length of 2 year old and older wood	1,225 cms.	785 cms.
No. fruit buds (on spurs)	26	36
No. fruit buds per 100 cms. old wood	2·1	4·6

The sprayed branches produced two to three times as many fruit buds on spurs than the untreated branches. On the unsprayed branches large numbers of leaf buds remained dormant instead of developing into spurs—a general failing of the Bon Chrétien variety in the Stellenbosch area. With the sprayed branches, however, fruit spurs were produced freely on two year old and three year old wood.

TABLE XXV.

Effect of Raw Linseed Oil Emulsion on the Formation of Fruit Buds on one year old shoots (Bon Chrétien, 1934-35).

	Unsprayed (8 branches).	Sprayed (Aug. 17th) (6 branches).
Tree No. 1.		
Total length of shoots	2,601 cms.	2,054 cms.
Total No. of fruit buds on shoots	93	160
No. of fruit buds per 100 cms. of shoot growth ..	3·6	7·8
Tree No. 2.		
Total length of shoots	2,373 cms.	2,054 cms.
Total No. of fruit buds on shoots	104	133
No. of fruit buds per 100 cms. of shoot growth ..	4·4	6·5

Here again there is a striking difference in favour of the sprayed branches. The more normal growing conditions on the sprayed branches were probably more favourable for fruit bud differentiation than on the unsprayed branches.

During the course of the summer the time of fruit bud differentiation was studied and the results indicate that the oil treatment advanced the time of differentiation somewhat.

There is thus some truth in the belief amongst growers that better results are obtained with oil sprays in the second season of spraying. The reason is simply that in the year following the initial spraying there are more fruit buds present on the tree than would otherwise have been the case.

D. EFFECT OF OIL SPRAYS ON THE QUALITY OF THE FRUIT.

Samples of fruit of the same size were taken from sprayed and unsprayed branches and the specific resistance and the total solids in the sap determined.*

According to Reyneke (20) the higher the specific resistance and the lower the total soluble solids in the sap, the better the keeping quality of the fruit. Good quality is associated with high specific resistance and a relatively low percentage of "Total soluble solids". In Table XXVI the fruit from the sprayed branches invariably shows a higher specific resistance and a lower

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* Figures supplied by the Department of Agricultural Chemistry.

TABLE XXVI.

Specific Resistance and Total Solids of Fruit from Sprayed and Unsprayed Branches (Bon Chrétien).

Treatment.	Sp. Resistance (Ohms).	% Total Soluble Solids in Sap.
Unsprayed	331	12·36
Sprayed with 5% raw linseed oil emulsion on Sept. 3rd	373	11·81
Unsprayed	331	11·75
Sprayed	360	11·26

percentage of total solids than the fruit from unsprayed portions. These results are verified by storage tests with Bon Chrétien, as the following Table shows:

TABLE XXVII.

Condition of Bon Chrétien fruit stored at room temperature for fourteen days.

Treatment.	Pressure Test.	Condition of Fruit after Storage.
Tree No. 1.		
Unsprayed	4·75 lbs.	Condition varies; most of the fruit shows a dull greenish-yellow colour of ripeness.
Sprayed (Sept. 1st)	2·70 lbs.	Sound, uniform and full yellow colour.
Tree No. 2.		
Unsprayed	4·7 lbs.	Uneven ripening; dull greenish-yellow colour.
Sprayed ..	2·8 lbs.	Sound, uniform and well coloured.
B.C. Trees in Variety Orchard.		
Unsprayed	1·6 lbs.	Fruit unattractive greenish in colour; uneven ripening.
Sprayed ..	0·5 lb.	Well coloured and sound.

The pears of the sprayed branches ripened very uniformly, developing a bright attractive yellow colouring throughout. The fruit from the unsprayed portions developed a conspicuous greenish-yellow appearance, but the colour varied considerably, even though the fruit was quite ripe and edible.

Similar results were obtained with the Glou Morceau variety, but here the fruit was first put in cold storage for three weeks and then stored at ordinary room temperature for another three weeks. The fruit of the unsprayed portions of the tree showed a high percentage of greenish-yellow fruit (35 per cent.) whereas the pears from the sprayed branch ripened up normally. The latter also showed less wastage than the former.

SEED CONTENT OF FRUIT.

After storage the pears were cut open and the seed content determined.

TABLE XXVIII.

Effect on Seed Content: Bon Chrétien (Variety Orchard).

Treatment.	% Fruit without any Seeds.	Average No. of Seeds per Fruit.	
		Poorly Developed Seeds.	Normal Seeds.
Unsprayed	40	8·2	1·7
Sprayed (Sept.) ..	0	4·3	5·4
Glou Morceau (Variety Orchard).			
Unsprayed	8·3	5·4	2·5
Sprayed	0	2·0	5·2

From the above Table it is quite clear that the pears from the oil treated branches were more normal with respect to seed content than those from unsprayed branches. According to Reinecke (19) self-fruitful pear varieties usually develop parthenocarpically with self-pollination, but the above varieties were both in a variety orchard where there were ample facilities for cross-pollination.

However, it may be possible that bees were more attracted by the sprayed branches which blossomed earlier and more evenly than the other parts of the trees, thus effecting a more thorough cross-pollination. On the other hand, the effect may have been more directly due to the more normal development of the "treated" fruit from blossoming stage to maturity.

In any case the difference in quality appears to be largely due to the difference in seed content; Reinecke (19) has shown that the seed content may profoundly affect the composition and keeping quality of pears.

E. VARIETAL RESPONSE TO OIL SPRAYS.

In 1934 comparative tests were made on the following pear varieties: Bon Chrétein, Louise Bonne, Kieffer, Fertility, Winkfield, Beurré Hardy, Duchess d'Angouleme, Tongres, Magnate, Beurré Diel, Forelle, Glou Morceau, Beurré Bosc, Clapp's Favourite, Winter Nelis, Packham's Triumph. On each tree a single scaffold branch was sprayed throughout with a 5 per cent. raw linseed oil emulsion and all varieties were sprayed on the same date, viz. September 1st. During the course of the summer observations were made on the blossoming and foliation of the trees and the varieties classified according to their response to oil treatment.

(a) *Varieties on which oil treatment shows very marked effects:* Glou Morceau, Bon Chrétien, Beurré Hardy.

(b) *Varieties which respond moderately well:* Beurré Bosc, Clapp's Favourite, Winkfield, Tongres, Beurré Diel, Winter Nelis.

(c) *Varieties which show only a slight response:* Louise Bonne, Duchess, Magnate, Packham's Triumph.

(d) *Varieties on which there is no or very little effect:* Kieffer, Forelle.

The degree of response to oil treatment appears to be correlated with the susceptibility of the variety to "delayed foliation". Varieties such as e.g. Kieffer, which are highly resistant to "delayed foliation", show very little response whereas susceptible varieties, e.g. Bon Chrétien, Glou Morceau, are readily influenced by oil sprays. As has been shown previously, the Bon Chrétien can be benefited by oil treatment even in a fairly normal season such as 1933.

DISCUSSION.

In this report an attempt has been made to show that dormant oil sprays can be of great commercial value to deciduous fruit growers by virtue of their beneficial effects on fruit production and on tree growth in general. The oil treatment apparently has the effect of breaking the rest period of the fruit buds and leaf buds at a critical stage, thus causing the tree to develop more normally under climatic conditions which cause protracted blossoming and foliation in spring. At this stage, no scientific explanation is offered to account for this stimulation, but this phase of the subject is receiving further attention. Other artificial methods have been known to break the rest period of fruit trees; none has proved as economical and as effective in practice as oil sprays. Many of the mineral oil sprays are good insecticides and are used as such in general orchard practice to-day.

Some of these oils, as this work shows, stimulate tree growth and should be preferable to raw linseed oil, since the latter, although a good stimulant, has not proved itself a good insecticide. A factor of importance is the timing of the spray. The buds appear to react best to oil treatment at a certain critical stage; furthermore the fruit buds show their optimum response at a somewhat earlier stage than the leaf buds. For the varieties studied in this experiment (and it may well apply to most varieties of apple and pear in the Stellenbosch area) the latter half of August proved to be the most suitable time for spraying. Mally (15) is of opinion that oil sprays should be applied four weeks before the blossoming period of the variety. But it is well-nigh impossible to forecast the actual date of blossoming of a variety for any particular season, since time of blossoming is not a constant factor. It may vary according to season, site of orchard, soil conditions, etc. In our experiments the best spraying date varied from four to eight weeks before the first opening of blossoms.

The data in this report deal exclusively with apples and pears. A certain amount of work was also done on plums and the preliminary results suggest that some varieties of Japanese and European plums respond remarkably well to oil treatment. With peaches the results were less satisfactory and further work is required before any definite recommendations can be made. But growers are warned against the indiscriminate use of oil sprays on peaches because of the danger of spray injury. In conclusion it may be well to bear in mind that oil sprays, like all artificial measures, have their limitations and even under the most appropriate conditions, they can never be expected to give quite the same results as a naturally favourable environment.

The Imperial Bureau of Fruit Production has kindly taken the responsibility for final proof reading of this paper, in order that its publication may not be unduly delayed.

SUMMARY.

1. A dormant spray of raw linseed oil emulsion (5 per cent.) had a stimulating effect on the fruit buds of Bon Chrétien and Beurré Hardy pears and White Winter Pearmain apples, causing an earlier, a more prolific and a more even bloom.

2. Similar stimulating effects were obtained during one season's work with seal oil and two proprietary mineral oil emulsions, notably on the Ohenimuri apple and Bon Chrétien pear.

3. Oil treatment also had a marked effect on the leaf buds. It caused fewer buds to remain dormant, resulting in more spurs and shoots being formed ; moreover, it promoted an earlier and a more regular growth, also an earlier cessation of the growing season.

4. The degree of stimulation of fruit and leaf buds by oil sprays varies with

(a) Time of spraying.
(b) Variety.
(c) Season.

For the fruit buds, mid-August generally proved the most effective spraying date, whereas for the leaf buds end-August gave better results in most cases. However, since there is no considerable difference in effect between these two spraying dates, the latter half of August may be regarded as a suitable time for spraying the varieties used in this experiment.

The reaction of a variety to oil treatment depends upon its adaptability to climatic conditions which favour "delayed foliation". The more susceptible it is, the more readily will it respond to oil treatment.

Likewise the oil effects are less striking in a fairly normal season such as 1933 than in " delayed foliation " years such as 1934 and 1935.

5. Oil sprays led to a considerable increase in yield of Bon Chrétien as a result of the more normal blossoming. Fruit quality, especially the storage properties of the fruit, were enhanced.

Furthermore the bearing capacity of the tree was increased, due to more fruit buds being differentiated on both spurs and on shoots.

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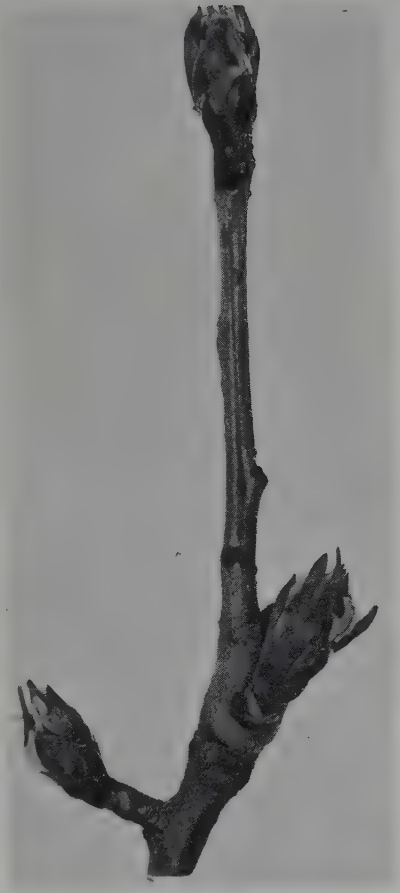

FIG. 1.

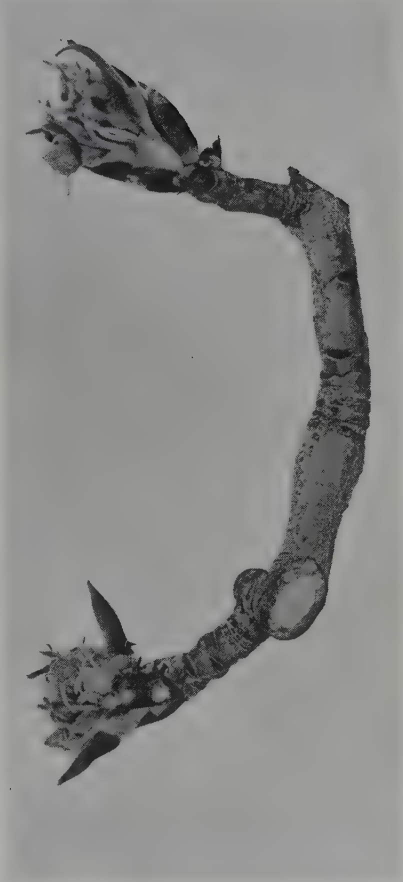

FIG. 2.

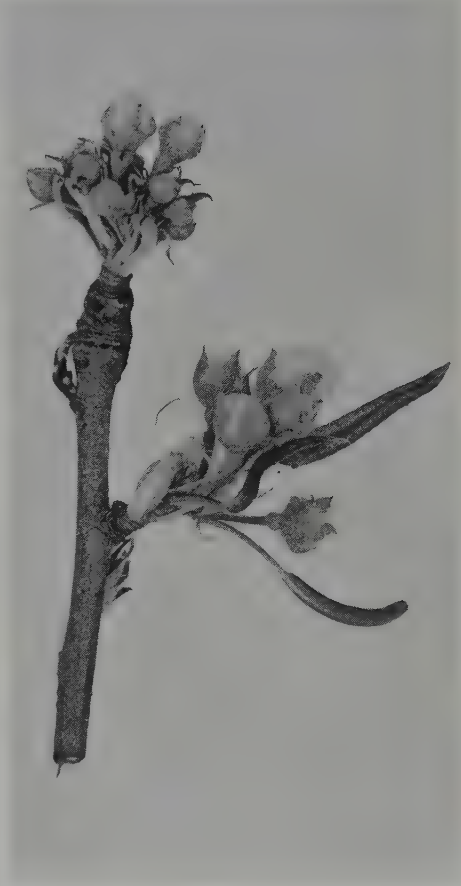

FIG. 3.

Stages of Blossoming in Pears.

Swelling— Bursting Stage (Fig. 1). Cluster— Pink Stage (Figs. 2 and 3).

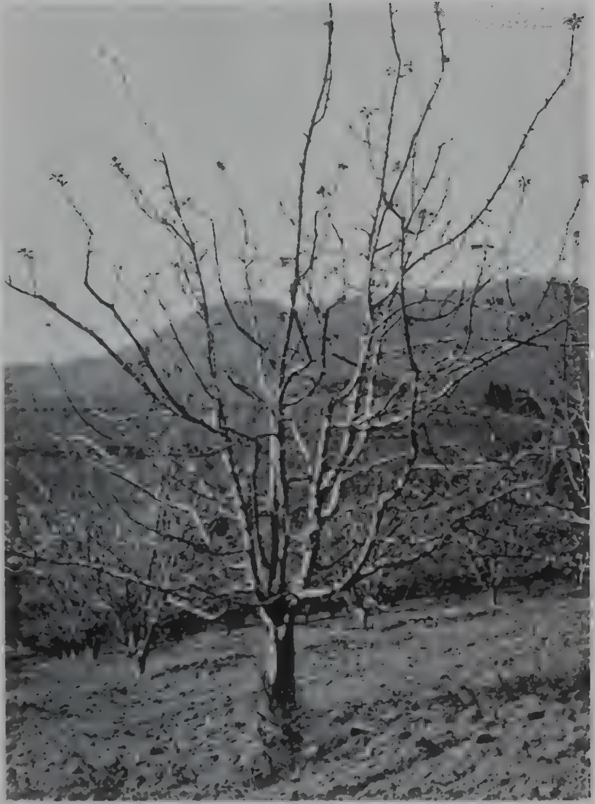

Fig. 4.
Ohenimuri Apple Tree. Unsprayed (Elgin, 1935). Note very irregular blossoming

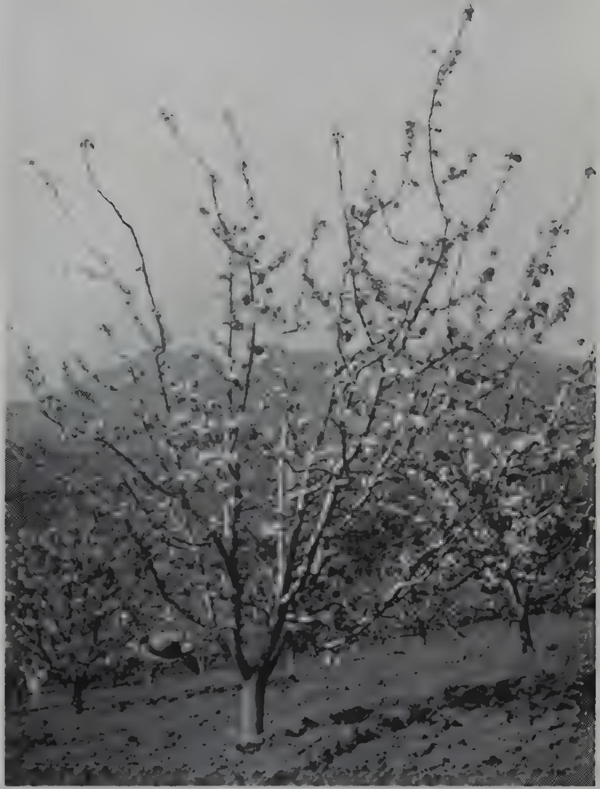

Fig. 5.
Ohenimuri Apple Tree sprayed with mineral oil Kp (5 %) on August 21st (Elgin, 1935). Compare even blossoming with Fig. 4.

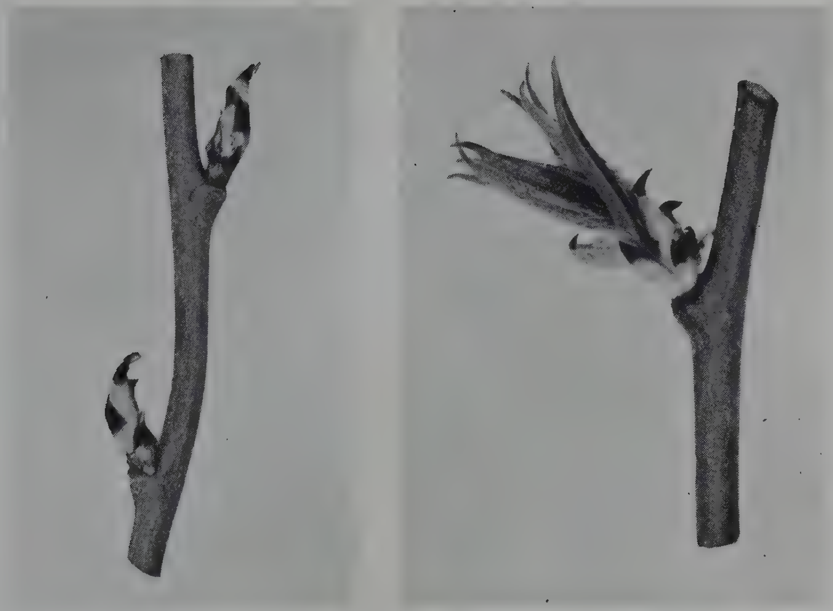

Fig. 6. Fig. 7.

Stages of Development of Leaf Buds,
showing Swelling-Bursting Stage (left) and Leaf Cluster Unfolding (right).

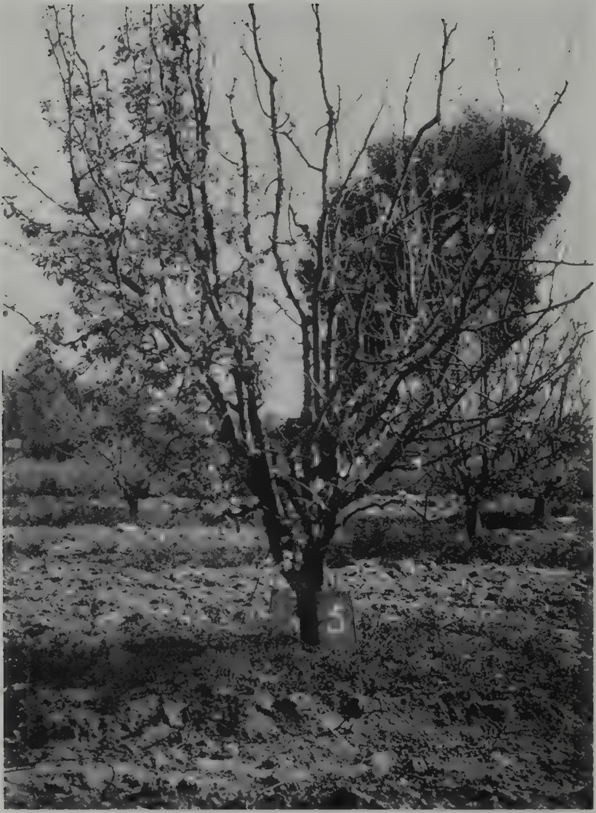

Fig. 8.

Typical Half-sprayed Bon Chrétien Pear Tree; Left half sprayed (Seal Oil, August 17th); Right half unsprayed. Photographed six weeks later.

METAXENIA IN APPLES. V

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In a series of previous experiments (Nebel 1930, Nebel and Trump 1932, Nebel 1932) summarized by Nebel and Kertesz (1934) the influence of the male gamete on the apple immediately produced has been traced. In the experiments reported in 1934, McIntosh apples were differentially pollinated with Red Astrachan and Yellow Bellflower in one set of tests and with Red Astrachan, Malus baccata and Malus atrosanguinea in another set of experiments. The Red Astrachan pollen, when compared with that of Yellow Bellflower, produced a slightly heavier crop on the average of five comparative weighings. Juice from the apples having Red Astrachan as a male parent consistently showed greater acidity, giving a significance of 1,341 : 1 in terms of odds when compared with apples produced with Yellow Bellflower pollen. Higher acidity in the juice from the McIntosh cross having Red Astrachan as a male parent also appeared when compared with Malus baccata used as the differential male. In this combination a difference was reported for catechol tannin. This, it is realized, may have been caused by an actual difference in acidity, the juice of the Red Astrachan cross requiring a greater amount of alkali in the test and thus apparently showing less catechol tannin than the juice of the Malus baccata cross with which it was compared.

Since in all of the thirteen series of chemical tests reported upon to date the utmost care was taken to compare only apples of exactly the same age and size using duplicate and triplicate samples of at least five apples each in every determination, these experiments are believed to be the most significant evidence yet presented of metaxenia as a distinct phenomenon in the apple.

A further experiment on metaxenia was carried out in 1935. This time McIntosh was crossed with Wilson Red June and with Boiken respectively. The following Table gives the results:

	Cross.	
Character observed.	*McIntosh × Wilson Red June.*	*McIntosh × Boiken.*
Total number of fruits harvested 9/12/34 ..	51	41
Mean weight of fruit in gm.	69·2	72·5
Mean weight of 10 small apples used for chemical samples	67·3	66·6
Average seed number of small apples	7·6	7·8
Mean weight of 10 large apples used for chemical test	78·8	78·7

Character observed.	*Cross.* *McIntosh* × *Wilson Red June.*	*McIntosh* × *Boiken.*
Average seed number of large apples	7·8	8·1
pH of juice of small apples	3·24	3·2
pH of juice of large apples	3·25	3·25
Acidity (cc. M/10 KOH) small apples ..	7·8	7·4
Acidity (cc. M/10 KOH) large apples ..	7·4	7·8
Average seed number of remaining apples ..	7·6	6·6
Average per cent. loss of weight of remaining apples stored 9/12/34 to 6/8/35	10·7	10·5
Percentage of apples rotted during storage ..	0	47·6

The Table shows that the two groups of apples were extremely similar in all characters under observation save the last. After nine months of storage the apples of the Wilson Red June cross showed only slight internal browning and no rotten spots. The corresponding group of the Boiken cross showed five apples completely rotten and five with large rotten spots.

The present experiment, very much as previous ones, emphasizes the complexity of the problem under question. It confirms previous conclusions that metaxenia may affect one character out of several observed not affecting the others. If in the present experiment rotting was differentially affected, this again shows how the pollen may perhaps carry into the zygote a differential rate of metabolism which in turn indirectly causes a reflection in the metabolism of the surrounding fruit tissue which, while admittedly small, is yet detectable under accurate observation.

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THE COMPOSITION OF ORANGE SKINS

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In a previous paper (1) dealing with the changes in the composition of oranges during ripening, the composition of the juice and pulp was studied together with the effect upon the composition of the juice of spraying the trees with lead arsenate. At the time it was thought that an investigation of the composition of the skin might assist in throwing some additional light upon the action of the lead arsenate spray. The required material was obtained by using the skins from the oranges used in the major investigation. It is proposed to deal with the results obtained with the skins during the same period of ripening as in the above work. Apart from the purely theoretical aspect of this work, a knowledge of the composition of the skin of the orange has a practical value from the point of view of storage and transport, as well as owing to the growth of interest in the citrus by-products industry.

In general, the amount of work done on the composition of fruit-skins does not appear to be very great. In most cases the skin of a fruit is difficult to separate completely and frequently must be regarded as being co-extensive with the pulp. In the cases of oranges and other citrus fruits, the easy separation of the skin simplifies the problem of obtaining material for analysis. In addition, slightly more work has been done in the case of orange skins for two further reasons. Firstly, the skin forms an abundant source of pectin and secondly, it has a fairly high percentage of essential oil. Both these products have a high commercial value. However, no detailed study has been made of the changes of the constituents of the peel during an extended period of ripening. Haas and Klotz (6) in dealing with the physiological gradients in citrus fruits have published data for the mineral constituents of orange peel but no attempt has been made to follow the changes over a period of time. de Villiers (3) has discussed the possibility of extracting the essential oil from the skin of cull oranges at great length in several papers and has touched upon the extraction of pectin. Nanji and Norman (9) have determined the amount of pectin from orange skin in the form of pectin, pectose and pectates, but this work was mainly devoted to a study of the methods of estimation. McDermott (8) has studied the enzymes of the peel but made no analysis of the skin. The present author (2) has published some data for the nitrogen content of orange skin.

The oranges used in the investigation were those of the Washington Navel variety and were obtained from the Eastern Districts of the Cape Province. The samples of skin corresponded with the mixed samples of juice which had been preserved for the determination of nitrogen in the work on the composition of oranges (1). After the juice had been expressed by means of a lemon squeezer and the pulp or "rag" removed, a weighed quantity of the skin was dried sufficiently to be coarsely powdered and the material preserved in tightly corked bottles with a coating of paraffin over the cork. The initial loss of weight was determined so that the total loss of weight could be determined when the skin was finally and completely dried. The resulting data could therefore be calculated in terms of the original fresh weight of the skin. In each weekly batch of samples at least four separate samples of mixed skin were preserved in the two series of sprayed and unsprayed fruits. The treatment to which the samples had been subjected has already been fully described (1).

In analysing the ash the determinations were limited to the content of lime, potash and phosphoric oxide, using the methods adopted in the case of the juice. Four separate portions of the completely-dried and well-powdered skin were used. In one portion the ash and its constituents were determined. In a second portion the sugar content was determined by first extracting with 80 per cent. alcohol, evaporating the alcohol from the extract, dissolving the residue in water and making up to known volume. The aqueous solution was cleared with lead acetate and potassium oxalate and the sugars determined by Hane's modification of the Hagedorn and Jenson method (7). Both total and reducing sugars were determined but, on account of the uncertainty regarding the amount of hydrolysis occurring during the drying of the skin, only the total sugar in terms of invert sugar is reported. In a third portion of the dried skin the total pectin was determined by the method outlined by Nanji and Norman (9). The material was extracted with 0·5 per cent. ammonium oxalate and the total pectin in the extract determined as calcium pectate according to the method developed by Emmett and Carré (4) for the precipitation of pectin. In a fourth portion of dried skin the nitrogen was determined by the usual Kjeldahl method.

The data, so obtained, may be reported in several ways. In order to compare any one constituent in the skin with the corresponding constituent in the pulp, the data for the latter will also be reported. The results may be expressed in terms of:

A. The absolute weight of the constituents per fruit.
B. The amount per 100 grams of pulp and per 100 grams of skin.
C. The amount per 100 grams of dry weight in each case.
D. The amount per 100 grams of ash in the case of the ash constituents.

In the case of the pectin, this constituent was determined only in the skin and will therefore be reported simply in terms of 100 grams of dried skin.

Before discussing the changes and magnitudes of the various factors, the question must be considered whether spraying with lead arsenate has had any effect upon the composition of the skin. In the case of the pulp it has been shown (1) that there is a direct effect upon the acid and the alcohol-insoluble residue. Any existing differences in the other factors in the sprayed and unsprayed fruits were shown to be due to inherent differences in the trees. In the case of the skins it has been found that, where the differences in the mean values of the factors were significant, there was no significant change in these differences with time. The differences persisted, more or less constant in magnitude, throughout the period of the investigation. For example, the amount of pectin in the dry skin was slightly greater in the sprayed fruit than in the unsprayed, the difference being 1·02 and significant. This difference remained more or less constant during the whole period and showed no significant change. It seems that this must be due to the inherent characteristics of the trees in the two series. It would certainly be expected that, if spraying with lead arsenate has any effect upon a given constituent, the difference will be either increased or decreased significantly with time. A similar conclusion can be drawn in regard to other factors in the skin and it must be concluded that the present results do not indicate that spraying has any direct effect upon those constituents of the skin which were investigated. On this account only the mean values from the sprayed and unsprayed series will be reported in order to condense the mass of data obtained, and simplify the treatment of the results.

A.

The distribution of the constituents between the pulp and the skin may be indicated by the absolute weights per fruit of the constituents in the pulp and in the skin. These data are given in Table IA and IB (page 208) in terms of grams per fruit.

On comparing the absolute amounts of the constituents in the pulp and in the skin several interesting facts emerge. There is about twice as much sugar in the pulp as in the skin, while there are about approximately equal amounts of mineral matter and nitrogen in these two parts of the fruit. The amounts of potash and phosphoric oxide are very much greater in the pulp than in the skin, but the skin contains about fifty times as much lime as the pulp. If lime is an essential element in the cell-wall structure such a distribution might be expected.

The changes in the various factors with time may usually be more readily followed by means of curves. With the present data the scatter in the points is fairly wide and it is almost impossible to fit a continuous curve with any exactitude. It was found that the changes could be assumed to be linear without introducing any serious error and, since this renders comparisons simple, this has been done in all cases. The daily rate of change can be easily calculated and its significance tested by the " t " method of Fisher (6). The results are given in Table II.

TABLE IA.

Constituents in the Pulp.

Time in days.	Invert Sugar.	Nitrogen.	Ash.	Potash.	Lime.	Phosphoric oxide.
0	10·5	0·14	0·45	0·21	0·024	0·062
12	11·5	0·12	0·46	0·23	0·027	0·055
19	12·0	0·14	0·48	0·23	0·028	0·067
26	13·1	0·14	0·51	0·24	0·028	0·052
33	13·0	0·15	0·49	0·23	0·028	0·045
41	13·1	0·13	0·46	0·23	0·025	0·042
48	15·4	0·14	0·51	0·25	0·030	0·048
62	14·8	0·18	0·59	0·31	0·028	0·048
69	15·9	0·16	0·54	0·28	0·030	0·050
76	16·1	0·16	0·57	0·30	0·029	0·054
83	17·1	0·21	0·69	0·37	0·035	0·064
89	16·2	0·18	0·58	0·30	0·029	0·056
Mean	14·04	0·154	0·527	0·265	0·0284	0·0536

TABLE IB.

Constituents in the Skin.

0	4·6	0·14	0·46	0·16	0·14	0·031
12	4·9	0·14	0·47	0·16	0·15	0·025
19	5·2	0·14	0·46	0·17	0·13	0·025
26	5·4	0·14	0·49	0·17	0·14	0·023
33	6·1	0·15	0·49	0·18	0·14	0·025
41	7·1	0·14	0·47	0·16	0·14	0·024
48	8·5	0·18	0·54	0·18	0·16	0·029
62	8·2	0·16	0·51	0·18	0·14	0·027
69	9·1	0·17	0·54	0·19	0·15	0·031
76	9·2	0·16	0·53	0·19	0·15	0·031
83	9·2	0·17	0·57	0·21	0·14	0·031
89	8·5	0·15	0·51	0·18	0·13	0·029
Mean	7·15	0·153	0·502	0·177	0·142	0·0274

TABLE II.

Constituent.	Pulp.			Skin.		
	Rate.	" t."	Rel. Rate.	Rate.	" t."	Rel. Rate.
Invert Sugar ..	0·0700	10·8	0·500	0·0584	8·7	0·817
Nitrogen ..	0·00075	6·0	0·487	0·00034	10·0	0·222
Ash	0·00204	5·3	0·387	0·00104	4·6	0·207
Potash	0·00145	6·1	0·550	0·00041	5·4	0·240
Lime	0·00007	3·1	0·236	0·00002	0·2	0·014
Phosphoric oxide	−0·00003	0·4	−0·056	0·00003	1·1	0·125

The value of " t " for a significance of 20 to 1 should be at least 2·23 and it will be seen that, except for the lime in the skin and the phosphoric oxide in both the skin and the pulp, the various factors increase in amount during ripening. Since the weight of the fruit itself increases during this period, an increase in the amounts of the various constituents would be expected. Where there is no significant increase it must be assumed that, in such a case, the supplies of the particular constituent must be laid down in the early stages of formation of the fruit. Phosphoric oxide is an example of such a constituent.

If the relative rate of change, as measured by the factor Rate/Mean Value, be considered as a means of comparison in place of the absolute rate, some interesting results are apparent. Contrary to expectation the sugar increases at a relatively greater rate in the skin than in the pulp. The absolute amount of nitrogen, ash, potash and lime increases at a relatively greater rate in the pulp, generally about double the rate in the skin. This would seem to point to greater metabolic activity in the pulp during the growing period.

TABLE IIIA.

Constituents in Fresh Pulp.

Time in days.	Invert Sugar.	Nitrogen.	Ash.	Potash.	Lime.	Phosphoric oxide.
0	8·6	0·11	0·37	0·17	0·021	0·051
12	8·8	0·10	0·36	0·18	0·021	0·043
19	8·6	0·10	0·35	0·17	0·020	0·048
26	9·6	0·10	0·37	0·17	0·021	0·038
33	9·3	0·11	0·35	0·17	0·020	0·032
41	9·6	0·10	0·34	0·17	0·018	0·031
48	9·9	0·09	0·33	0·16	0·019	0·031
62	9·6	0·11	0·38	0·20	0·018	0·031
69	9·8	0·10	0·34	0·17	0·019	0·031
76	9·9	0·10	0·35	0·19	0·018	0·033
83	9·9	0·12	0·40	0·22	0·020	0·038
89	10·3	0·12	0·37	0·20	0·019	0·036
Mean	9·50	0·105	0·358	0·179	0·0194	0·0368

TABLE IIIB.

Constituents in Fresh Skin.

0	8·1	0·25	0·81	0·28	0·25	0·055
12	7·8	0·22	0·74	0·26	0·23	0·040
19	8·7	0·23	0·77	0·28	0·21	0·042
26	8·5	0·23	0·77	0·27	0·22	0·037
33	9·7	0·24	0·79	0·27	0·23	0·039
41	10·6	0·21	0·70	0·24	0·21	0·035
48	11·1	0·23	0·71	0·23	0·21	0·037
62	10·5	0·21	0·65	0·24	0·18	0·035
69	11·0	0·20	0·65	0·23	0·18	0·037
76	11·4	0·20	0·65	0·23	0·18	0·038
83	10·7	0·20	0·67	0·24	0·16	0·036
89	11·5	0·20	0·69	0·25	0·18	0·039
Mean	9·97	0·217	0·717	0·252	0·203	0·0391

B.

The proportions of the above constituents per unit of fresh weight will perhaps give a clearer idea of the relative distribution of these factors in the composition of the pulp and the skin. The mean values for these factors are given in Table III (page 209) in terms of grams per 100 grams of fresh weight.

On examining the results in Table III it will be seen that somewhat unexpectedly the proportions of the various constituents tend to be higher in the skin than in the pulp. The difference in the case of the invert sugar is not significant ("t" = 1·84), although it tends to increase with ripening since, as will be shown, the proportions of sugar in the skin increase at a greater rate than in the pulp. The proportion of ash and nitrogen in fresh skin is double that in the fresh pulp. This result would seem to be related to the problem of cell-structure, the skin being of a closer texture than the pulp. The proportion of potash is about 50 per cent. greater in the skin than in the pulp. This is in accordance with the conclusion of Haas and Klotz (6) who found that the concentration of potash was not generally greatest where the concentration of sugar was greatest. The concentration of lime in the skin was ten times greater than in the pulp. The proportions of phosphoric oxide in the skin differed from that in the pulp by 0·0023, but the difference was not significant ("t" = 1 : 85).

In connection with the changes which take place with time the same remarks may be made as in the case of the absolute weights. The results are given in Table IV.

Table IV.

Constituent.	Pulp.			Skin.		
	Rate.	"t."	Rel. Rate.	Rate.	"t."	Rel. Rate.
Invert Sugar ..	0·0168	6·6	0·177	0·0413	7·1	0·414
Nitrogen ..	0·00016	1·6	0·150	−0·00057	3·4	−0·263
Ash	0·00016	0·7	0·045	−0·0017	5·1	−0·237
Potash	0·00038	2·7	0·212	−0·00051	3·8	−0·202
Lime	−0·00003	3·3	−0·155	−0·00085	8·0	−0·416
Phosphoric oxide	−0·00015	2·6	−0·416	−0·00011	2·5	−0·277

In both cases the proportion of sugar increases significantly with time, but, as might be expected from the changes in the absolute amounts, the relative rate is very much greater in the skin. The proportions of nitrogen and ash in the pulp do not increase significantly with time as has already been pointed out in a previous paper (1). In the skin both these factors show a significant decrease with lime. The proportion of potash in the pulp increased significantly while the reverse was the case in the skin. In the case of lime and phosphoric oxide there are significant decreases with time both in the pulp and in the skin. The fact that there are decreases in the concentrations of certain factors seems to indicate that in these cases the supplies must be laid down in the early stages of growth. Such a conclusion would seem to indicate that these factors are more or less structural in function. In general the various factors tend to show a greater rate of relative change in the skin than in the pulp. A notable exception is the phosphoric oxide which decreases at a relatively greater rate in the pulp.

C.

When the results are expressed in terms of parts per 100 grams dry weight the contribution of each factor to the general make-up of the fruit can be more readily ascertained. As an additional factor the amount of pectin, calculated as calcium pectate, was determined in the skin. The pectin was determined only in the skin since this is the most important source of this compound in the skin. For the sake of brevity only the mean values of the factors are reported in Table V in terms of grams per 100 grams of dry weight.

TABLE V.

Pulp.

Invert Sugar.	Nitrogen.	Ash.	Potash.	Lime.	Phosphoric oxide.	Pectin.
75·92	0·840	2·87	1·43	0·157	0·297	—

Skin.

Invert Sugar.	Nitrogen.	Ash.	Potash.	Lime.	Phosphoric oxide.	Pectin.
41·13	0·893	2·95	1·04	0·833	0·162	22·33

The mean value for the pectin agrees well with that found by Nanji and Norman (9) in their work on orange peel. The amount of pectin in the skin of the sprayed fruit was slightly higher than in the unsprayed fruit, but the differences were not consistent and it was concluded that the difference was due to inherent characteristics of the trees. It would appear that, in the skin, the pectin must play nearly as important a part as the sugar in the metabolism of the fruit. It will be seen that the amounts of sugar in the dry pulp is very nearly double the amount in the dry skin. This indicates the predominant part played by the sugar in the pulp. The amounts of ash and nitrogen in the dry matter are very nearly the same in both cases and it seems that a close relationship must exist between these two factors. This point will be discussed later. The amounts of potash and phosphoric oxide are greater in the dry pulp than in the dry skin while the reverse is the case with lime. The above results for the ash constituents in the pulp are slightly lower than the corresponding results given by Haas and Klotz (6).

The daily rate of change for each factor has been treated in the same way as previously and the results are given in Table VI.

TABLE VI.

	Dry Pulp.			Dry Skin.		
Constituent.	Rate.	" t."	Rel. Rate.	Rate.	" t."	Rel. Rate.
Pectin	—	—	—	0·0306	2·7	0·140
Invert Sugar ..	0·0436	3·3	0·057	0·185	7·7	0·450
Nitrogen ..	0·00022	0·3	0·026	−0·0017	7·7	−0·185
Ash	−0·0028	1·5	−0·097	−0·0058	6·4	−0·196
Potash	0·0013	1·1	0·090	−0·0017	2·5	−0·163
Lime	−0·0004	4·9	−0·270	−0·0031	9·7	−0·378
Phosphoric oxide	−0·00165	3·2	−0·556	−0·0004	2·3	−0·238

The relative amount of pectin in the dry skin increases at a significant rate and it appears that during the growth of the fruit there must be a continual production of cell-wall tissue. The amounts of sugar in the pulp and in the skin show significant rate of increase but the relative rate is very much greater in the skin. The amount of nitrogen in the dry pulp tends to increase but the change is not significant ; in the case of the dry skin there is a significant rate of decrease. In the case of the skin all the mineral constituents decrease significantly with time and with the exception of the phosphoric oxide the relative rates are greater in the dry skin than in the dry pulp. It would appear that the mineral constituents of the skin are laid down in the early stages of growth and that subsequently there is little or no demand upon the mineral stores in the skin.

D.

Finally, the ash constituents may be expressed in terms of 100 grams of ash. Differences between the sprayed and unsprayed fruits were only significant in the case of lime. At the same time, while the lime content of the ash was higher in the pulp of unsprayed fruits, the reverse was the case with the lime of the ash of the skin. It may therefore be concluded that these differences were not due to spraying with lead arsenate.

The mean values for the ash constituents are given in Table VII.

TABLE VII.

	Potash.	Lime.	Phosphoric oxide.	Total.
Constituents of Ash of Pulp ..	49·9	5·5	10·4	65·8
Constituents of Ash of Skin ..	35·3	28·3	5·4	69·0

In both cases the three constituents account for about 65-70 per cent. of the total ash. The most notable point about these results is the very much greater proportion of lime in the ash of the skin compared with the proportion in the pulp. This would accord very well with the assumption that lime is closely related to the cell-wall structure of the fruit.

The values for the daily rates of change of these factors in the ash are given in Table VIII.

TABLE VIII.

	Pulp Ash.			Skin Ash.		
Constituent.	Rate.	"t."	Rel. Rate.	Rate.	"t."	Rel. Rate.
Potash	0·0824	6·4	0·165	0·0160	1·3	0·045
Lime	−0·0104	4·7	−0·190	−0·0530	3·3	−0·188
Phosphoric oxide	−0·0494	3·6	−0·474	−0·0015	0·3	−0·027

The potash content of ash is the only factor which increases with time but the increase is significant only in the case of the pulp. The relative rate of decrease of the lime is about the same in both cases. The phosphoric oxide shows a significant rate of decrease only in the case of pulp.

RELATIONSHIP BETWEEN ASH AND NITROGEN.

In the examination of the variations in the various factors it has already been mentioned that a close relationship appeared to exist between the ash content and nitrogen content of the pulp and skin. Their proportions in the dry weight in both cases were very similar. It was found that there was a high degree of correlation between these two factors. Since the proportions for each factor were the same in the pulp as in the skin the two sets of data could be combined. The value of "r" was found to be +0·757 ("t" = 5·4; for a significance of 20 to 1, "t" should be 2·1). For the percentages in the dry weight the regression line was :

$$\text{Nitrogen} = 0{\cdot}34, \text{ ash } - 0{\cdot}124.$$

This relationship cannot be due to a partial correlation with the increase in weight of the whole fruit, since in the pulp the nitrogen tends to increase, while in the skin the reverse is the case. In the case of the ash there is a decrease with time both in the pulp and in the skin. The total nitrogen content may be regarded as a measure of the protoplasm present upon which the metabolic activity of the plant must depend. The source of nitrogen in the plant is mainly the soil and it would appear that the nitrogen is supplied to the tissues in some inorganic form. In such circumstances, since a large proportion of the ash consists of bases, it is possible that the ash plays some part as a carrier of nitrogen. In this case, a close relationship between the ash and nitrogen would be expected.

The author would like to express his thanks to Dr. B. de C. Marchand for the interest taken in this paper, and to the Imperial Bureau of Fruit Production for undertaking the proof correction.

SUMMARY.

The skins of Washington Navel oranges from lead arsenate-sprayed and from unsprayed trees growing in the Eastern Districts of the Cape Province were submitted to analysis at weekly intervals over a growing period of three months.

The methods of analysis are detailed.

The amount of pectin in the dry skin was slightly greater in the sprayed than in the unsprayed fruit, the difference, namely 1·02 being significant. This difference remained constant over a three month period and neither increased nor decreased significantly with time, as might have been expected, if lead arsenate had had any effect on a given constituent. The same was found with regard to other factors in the sprayed and unsprayed fruit, so that present results do not indicate that spraying has any direct effect on the skin constituents investigated.

The following constituents in the pulp and the skin were determined :—invert sugar, nitrogen, ash potash, lime, phosphoric oxide.

Results of analysis point to greater metabolic activity in the pulp during the growing period.

The fact that there are decreases in the concentrations of certain factors seems to indicate that in these cases the supplies must be laid down in the early stages of growth, and that these factors are more or less structural in function.

The factors with the exception of phosphoric oxide show a greater rate of relative change in the skin than in the pulp.

The pectin was determined (as calcium pectate) in the skin and mean values for this agree well with those of Nanji.

In the skin all the mineral constituents decrease significantly with time and, phosphoric oxide excepted, the relative rates are greater in the dry skin than in the dry pulp. This suggests that the mineral constituents of the skin are laid down in the early stages of growth.

The fact that the proportion of lime in the ash of the skin is much greater than that in the pulp accords well with the assumption that the lime is closely related to the cell-wall structure of the fruit.

A high degree of correlation was found between the ash content and nitrogen content of both the pulp and the skin. It is suggested that the ash may play some part as a carrier of nitrogen. [Summary by Imperial Bureau of Fruit Production.]

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ON VERTICILLIUM WILT OF THE PERPETUAL-FLOWERING CARNATION

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INTRODUCTION.

In a previous investigation (3) of the cause of " wilt " or " stem-rot " disease of the perpetual-flowering carnation it was found that diseased plants were infected by a number of *Fusaria*. The species most commonly encountered was *F. culmorum* and inoculation with this fungus reproduced several aspects of the disease. One aspect of the disease—infection through uninjured roots—was not satisfactorily accounted for and it was concluded that " some other factor not present in the above experiment is suspected ". Owing to lack of funds the investigation was discontinued.

In 1934, at the invitation of the grower, a visit was paid to the nursery on which most of the previous work was carried out. It was found that the incidence of " stem rot " had assumed more serious proportions and that many diseased plants were affected by a true vascular wilt, with lesions confined to the wood for distances of several feet. This type of plant was very prevalent on this nursery in 1934 whereas in 1927 most of the diseased plants examined and also those received from other nurseries showed the relatively shorter wood lesions associated with rotting of the pith, which characterizes infection by *F. culmorum*. The writer undertook, at the request of certain nurserymen, to investigate the cause of this true " wilt " disease.

The organism causing this disease proved to be the same as that shown by Wickens (4) to be *Verticillium cinerescens*, a fungus unknown to science until described by Wollenweber in 1929. Wickens does not appear to have isolated *V. cinerescens* during the first two years of his investigation and he points out that there is a tendency for this fungus to be overrun and obscured on isolation media by more rapidly growing *Fusaria*, which are present in the diseased plants as secondary invaders. The distribution of *Verticillium* wilt disease during the period of the writer's earlier investigation cannot now be determined but it is believed to have been considerably less extensive than in recent years. Dowson (2) does not record it.

The results of experiments, carried out in 1934 and 1935, are in agreement with the conclusions of Wickens, who finds three separate diseases on nurseries, which he calls *Verticillium* " wilt " caused by *Verticillium cinerescens*, *Fusarium* " wilt ", caused by *Fusarium dianthi*, and *Fusarium* " stem-rot ", caused mainly by *Fusarium culmorum*. The most serious aspect of disease in commercial carnation houses consists of areas enlarging from foci in the beds, the fungus presumably spreading through the soil, and invading uninjured roots of neighbouring plants. The fungus causing this disease is *Verticillium cinerescens*. *Fusarium culmorum* and a number of other *Fusaria* infest the basal portions of plants attacked by *Verticillium* but are not primarily responsible for this form of disease.

EXPERIMENTAL RESULTS.

(a) CAUSAL ORGANISM.

(*a*) *Isolations.*

From a typical badly affected bed thirty wilting plants were selected at random, divided into three groups of ten, and nearly four hundred isolations made by six different methods.

(1) Portions of woody tissues of diseased stems between the collar and the topmost main limb were transferred aseptically to slopes of nutrient agar.

(2) Portions of woody tissue taken to a distance of not less than 3 feet above the main limbs were transferred aseptically to slopes of nutrient agar. At least six isolations at 6-inch intervals were made from each plant.

(3) From similar material as in (2) 1-inch sections were cut at 3·5-inch intervals, surface sterilized and placed on plates of nutrient agar.

(4) Outgrowths were taken from similar material as in (2) when placed in a moist chamber.

(5) As (4) but the same portion of the plant used as in (1).

(6) Roots, after surface sterilization, were placed on nutrient agar.

The results are summarized as follows.

(1) Over 80 per cent. of the isolations made by method (2) yielded the same fungus, at least two cultures, free from any other organism, being obtained from each of the ten plants used. Although the topmost isolation was made from apparently healthy wood, this fungus was present in all cases but one, showing that its growth might extend for 3–4 feet up the stem before wilt occurred and that the limit of the infection was very difficult, if not impossible, to detect with the naked eye. The fungus was found to be identical with a type culture of *Verticillium cinerescens*, provided by the Bureau voor Schimmelcultures Baarn. The sixty-one isolates obtained by this method contained no fungus of the *Fusarium* group.

(2) The incidence of *Verticillium cinerescens*, in isolates obtained from similar material but by method (3) fell to 16 per cent. In contrast to isolations by method (2) the *Fusarium* group was strongly represented. That these fungi were growing in the tissue external to the wood was demonstrated by

(1) Their absence from isolations made directly from the wood.

(2) The occurrence of sterile plates showing that the method of surface sterilization used had been efficient.

(3) A tendency for adjacent isolations from the same stem to yield the same species.

Apparently there are a number of *Fusaria* that may infect superficially carnation stems and grow, presumably in the cortex, for distances as far apart as 2 feet.

(3) Of a series of eighty-one isolates from roots, *Verticillium cinerescens* was responsible for 6 per cent. In a second series of eighty-one isolates *Verticillium* was not found. *Fusaria*, the commonest being probably *F. culmorum*, and *F. scirpi var. acuminatum*, formed nearly half of the total organisms obtained. Six per cent. only of roots used were clean. The isolation from the seven main roots of one plant of six cultures (the remaining root being clean) of *F. culmorum*, *no other organisms being detected*, may be noted.

(4) Isolations from the region of the collar yielded mainly *Fusaria*.

The results of the isolation work suggested strongly that *Verticillium cinerescens* was the cause of the disease for it was obtained from 100 per cent. of diseased plants, provided that the method of isolation did not permit its presence to be obscured by more rapidly growing fungi. The second most common fungus, *F. culmorum*, was obtained from seven out of every ten plants examined.

(*b*) *Inoculations with Verticillium.*

Six young Spectrum plants in " thirty-two " pots were inoculated at soil level with *Verticillium cinerescens* (May 31st). By July 4th one of the five main limbs of a typical inoculated plant had wilted. By July 15th a second main limb had wilted and by July 24th the whole plant had succumbed. Similar observations were made on four other inoculated plants. The remaining plant had three wilted out of six main limbs on September 14th. *Verticillium cinerescens* was re-isolated from the woody tissues near the terminal growing points of the main limbs of all plants.

(*c*) *Inoculations with Fusarium.*

Inoculations in triplicate were made with twenty-one cultures, mainly *Fusaria*, representative of the fungi isolated from the cortex and roots of wilting plants. With one exception, apparently a strain of *Fusarium culmorum*, the results were negative, the inocula causing only a variable degree of local rotting at the point of inoculation. It is concluded that all these fungi were secondary and had invaded the tissues of the plant following primary infection by *Verticillium cinerescens*.

The results of these inoculations in conjunction with the isolation work led to the conclusion that *Verticillium cinerescens* is the causal organism of disease on the bed investigated. Isolations from similar plants received from other nurseries support the view that *Verticillium cinerescens* causes severe damage to the carnation crop.

(b) COMPARATIVE INOCULATIONS WITH *Verticillium cinerescens*, *Fusarium culmorum* AND *Fusarium dianthi*.

In August 1935 a parcel of fifteen plants, said to be suffering from "stem-rot" caused by *Verticillium cinerescens*, was received from a nurseryman. Two isolations to nutrient agar were made aseptically from the woody tissues of each plant. Thirty cultures of the same fungus were obtained, in twenty-three cases apparently free from other organisms. This fungus was subsequently found to be *Fusarium dianthi* (Prill et Del.). Careful search on the nursery of this grower failed to reveal any plants infected with *V. cinerescens* though "stem-rot" and "dieback" (in some cases extending beyond five joints), due to infection by *Fusarium culmorum*, were common.

Comparative inoculations were made with (1) *Verticillium cinerescens*, (2) *Fusarium culmorum* (a strain isolated from carnation plants in November 1925 and since kept in culture at this station), (3) *Fusarium dianthi* (a strain kindly supplied by Dr. G. M. Wickens). The results are shown in Table I.

TABLE I.

Inoculum.	Date of inoculation.	Number of inoculations.	Number of inoculated shoots showing wilt.	Mean date of wilt with S.E.	Apparent length of infected stem with S.E.
V. cinerescens	30.8.34	7	7	17.11.34 ± 6 days.	29·8 cm. ± 5·4
F. culmorum ..	—	6	5	11.9.34 ± 3 days.	3·5 cm. ± 0·3
F. dianthi ..	—	7	6	14.11.34 ± 7 days.	22·3 cm. ± 4·4
Controls ..	—	3	0	—	—

F. culmorum was responsible for a rapid wilt, characterized by rotting of all the tissues of the stem. Infection by *V. cinerescens* and *F. dianthi* was followed by a slower wilt, associated with extensive vascular infection. The fungi were readily re-isolated at some distance from the point of inoculation.

From superficial inspection of diseased plants on nurseries it is difficult to differentiate between the symptoms of these diseases. The following points are considered to be of value in diagnosis.

V. cinerescens.	*F. dianthi.*	*F. culmorum.*
Withering of shoots from the basal leaves upwards and on one side of the shoot only.	—	Wilting of shoots as a whole.
Infected plants not usually stunted.	Young shoots of infected plants distorted and stunted.	—
Extensive vascular browning not associated with cortex and pith lesions. (But cortex and pith lesions due to secondary infection by Fusaria are commonly associated with *Verticillium wilt.*) Dried stems firm to the touch.	Extensive vascular lesions, having a shredded silvery appearance, associated with "eating away" of the tissues bordering the wood. Dried stems owing to this "eating away" tend to be hollow to the touch.	Generalized rotting of pith, cortex and wood. Wood lesions do not usually extend more than a few cm. beyond the generalized rotting.
Longitudinal zoning of diseased woody tissues with gradual merging of healthy and diseased wood.	Longitudinal zoning of diseased woody tissues with sharp demarcation between healthy and diseased wood.	—

(c) INCUBATION PERIOD.

The incubation period of the disease may be estimated from inoculation experiments. The results of two experiments are shown in Table II.

TABLE II.

Number of plants.	Date of inoculation.	Number of days from inoculation to complete wilt with S.E.	Mean daily rate of growth of the fungus (cm.) with S.E.
7.	August 30th.	79 ± 6	0·38 ± 0·06
5.	May 31st.	57 ± 18	0·60 ± 0·03

The mean rate of growth of the fungus in the plant was determined by noting with a lens the apparent limit of the lesion in the wood, and is a minimal value, for on other occasions the fungus has been re-isolated from beyond this point. Re-isolations at this point yielded the fungus in each case. The mean rate of 0·6 cm. per day during June and July compares with a mean rate of 0·4 cm. per day during September and October. A mean rate of an order of 0·5 cm. per day would correspond with complete wilt of plants in their second year about three months after root infection. This would place the period of maximal infection of commercially grown second year plants, a type in which the disease is frequently first apparent, in late winter, for the period of maximal wilt is in May and June.

(d) TRANSFERENCE OF THE DISEASE BY CUTTINGS.

(1) Sixty-seven cuttings from apparently healthy plants on a bed containing diseased patches were taken by a nurseryman, as if for his propagation, and handed to the writer, who cut off the base of each, sterilized the exterior and placed it on nutrient agar. Fifty-eight per cent. were clean, thirty-five per cent. contained fungi not suspected of causing wilt and seven per cent. fungi provisionally identified as *Verticillium cinerescens*.

(2) Seventy-two similar cuttings were supplied to the writer, who split open their bases with a sterile knife, dissected out the wood with a pair of sterile forceps over a porcelain plate, frequently wiped with 0·1 per cent. Hg. Cl_2, and placed them on slopes of nutrient agar. The results were as follows :—

	per cent.
Clean cuttings	40
Cuttings containing fungi not suspected of causing wilt ..	38
Cuttings containing fungi provisionally identified as *V. cinerescens*	15
Cuttings containing *Botrytis*	6
Cuttings containing *Fusarium*	1

Inoculation of carnation plants with the suspected fungi obtained from these cuttings was followed by wilt, and *Verticillium cinerescens*, free from other organisms, was re-isolated some distance from the point of inoculation in twenty-four out of thirty plants.

These results, which confirm those of Wickens (4), suffice to show that the *Verticillium disease may be transferred from crop to crop via the cuttings.*

(d) ON VARIETAL SUSCEPTIBILITY.

Thirty-two plants were inoculated by pricking *Verticillium cinerescens* into the basal joints of a single shoot. The inoculated shoots were all in a corresponding stage of development, and to ensure that this might be the case the plants were selected for uniformity out of a large number. Eight strains of *Verticillium cinerescens* were used and four plants, two of the variety Topsy and two of the variety Spectrum, were inoculated with a single strain. The inoculations were carried out on May 28th and on July 3rd the experiment was concluded by cutting out and slitting up the shoots with a sharp knife and noting the farthest point at which a lesion was apparent under a hand lens. This is not necessarily the limit of the distance to which the fungus had travelled but is assumed to represent in different plants equivalent stages of progress.

The results are shown in Table III, which suggests that four of the strains have been more virulent towards the variety Topsy, three show no appreciable differences and the remaining strain (No. 4) shows preference for the variety Spectrum. Fisher's analysis of variance has been used to compare the variance due to duplication of the inoculations with the variance due to strain, variety and the interaction between strain and variety. The results are shown in Table IV, from which the following conclusions are derived.

TABLE III.

Distances between Points of Inoculation and Apparent Limits of Lesions (cm.).

Strain.	Topsy.		Spectrum.	
1	17·6	14·2	17·8	14·5
2	16·3	20·3	14·5	18·2
3	22·5	28·1	11·1	16·8
4	10·5	12·6	16·0	19·5
5	24·7	24·4	12·6	13·7
6	27·0	29·2	15·8	10·7
7	18·7	24·5	18·3	12·2
8	24·7	20·0	11·4	8·3

TABLE IV.

Analysis of variance of relative pathogenicity of eight strains of Verticillium *towards two varieties. A value of "Z" greater than that in the 5 per cent. column denotes a significant difference in variability from that due to duplication of the inoculations.*

	σ d².	Degrees of freedom.	Variance.	"Z."	5% point.	
Between varieties	338·08	1	338·08	**1·854**	0·752	$n_1 = 1$ $n_2 = 16$
Between strains	115·68	7	16·53	0·345	0·490	$n_1 = 7$ $n_2 = 16$
Interaction between strains and varieties	377·22	7	53·89	**0·935**	0·490	$n_1 = 7$ $n_2 = 16$
Remainder (duplicate variation)	132·5	16	8·3	—	—	—

(1) In this experiment the variety Topsy has been more susceptible than the variety Spectrum. This was confirmed in the appearance of the plants, for at the termination of the experiment thirteen plants of Topsy were in varying stages of wilting, from the basal leaves upwards, whereas the corresponding number of Spectrum plants was six.

(2) There is no evidence of the occurrence of degrees of virulence between strains, which affect *both* varieties.

(3) There is definite evidence of differential susceptibility of varieties towards strains. Thus Topsy is the more susceptible variety to strains 3, 5, 6 and 8, but Spectrum is the more susceptible variety to strain 4.

(f) POSSIBLE RELATION BETWEEN INCIDENCE OF THE DISEASE AND THE LAYING OF A DRAIN.

Attention was directed by a nurseryman to a block of houses containing patches of diseased plants, extending across six beds, regardless of intervening paths while the spread of the patches along the beds was not extensive. In order to ascertain if this sequence was fortuitous a plan was made of these beds, each containing 283 rows, which were automatically divided into twenty-eight areas of ten rows each by plotting on graph paper. The occurrence of not less than six or more than fourteen consecutive diseased rows was arbitrarily considered to represent a single diseased patch, and a proportionately greater number of consecutive diseased rows represented further diseased patches.

The whole of the six beds consisted of 168 areas, which contained forty-four diseased patches. The odds against an area and diseased patch coinciding are thus $\frac{44}{168}=\frac{1}{3\cdot 8}$. The odds against the coincidence of six diseased patches occurring on a single sequence of six contiguous areas are $\frac{1}{(3\cdot 8)^6}=\frac{1}{2{,}930}$. But in the whole of the six beds there are twenty-eight such sequences. The odds against occurrence by chance of such a sequence of diseased patches throughout the block is thus $\frac{28}{2{,}930}=\frac{1}{105}$. These odds are greater than those conventionally considered to occur by chance and led to search being made for the cause of the distribution of the disease in this way. On representation to the grower the paths were dug disclosing a drain underlying the sequence of diseased patches. The most likely explanation of this effect would seem to be that it is not a direct consequence of the course of drainage but the result of upheaval of some unfavourable constituent of the subsoil when laying the drain.

(g) CROSS-INOCULATIONS.

Inoculations of Tomato, Chrysanthemum and Aster with *Verticillium cinerescens* have given negative results, although the Aster has previously been reported to be an alternative host. The specific pathogenicity of *Verticillium cinerescens* is fortunate as it may enable Tomatoes, Chrysanthemums and probably many other plants to be grown as alternative crops in badly-diseased carnation houses.

CONTROL MEASURES.

Successful control of the disease is clearly dependent on (1) elimination of the causal organism from diseased beds, (2) prevention of re-infection.

(1) Elimination of the Causal Organism from Diseased Beds.

(*a*) *Application of Fungicide to the Soil.*

The practical difficulty of penetrating portions of root containing the fungus and obtaining intimate contact with the soil particles, even in the absence of a growing crop, suggests that any such method is not a feasible proposition on a commercial scale.

(*b*) *Alternation of Crops.*

In comparative inoculation experiments, *Verticillium cinerescens* has so far failed to attack other plants, including the tomato. The possibility of cleansing the soil by growing several successive crops of tomatoes must not be overlooked.

(*c*) *Steam Sterilization.*

Steam sterilization is regarded as a standard method of controlling certain soil diseases of the tomato and there appears to be no reason why it should not also control *Verticillium* wilt of the carnation. Cases of alleged failure of steam sterilization to control disease in tomato houses, are frequently traceable to the use of the wrong method or its inefficient application. Similar cases are to be expected on carnation nurseries.

Brown (1) considers that contamination of the subsoil is a contributory cause of the re-appearance of the disease after steam sterilization. If this is the case the situation appears to demand, not the rejection of steam sterilization, but the introduction of a method suited for steaming to a lower depth. In the absence of an immune variety it is difficult to see how any effective and permanent control of *Verticillium* wilt in carnation houses can be secured without the use of steam sterilization.

(2) Prevention of Re-Infection.

It is clearly useless to carry out efficient sterilization of diseased beds if sources of re-contamination are neglected.

(*a*) *Cuttings.*

Cuttings taken from infected plants have been proved to contain *Verticillium* and it seems certain that the disease is carried in the stock, from the propagating house to the beds and is thus distributed over the nursery. Stock in transit from nursery to nursery must be considered suspect. In the absence of any method of bringing out the latent disease in young plants it would seem necessary in order to obtain stock 100 per cent. clean, to grow a generation in pots for the special purpose of propagation to the exclusion of bloom, as suggested by Wickens (2). Such a procedure would scarcely be practical as a permanent method of commercial propagation but might be undertaken for the purpose of cleaning stock, variety by variety. It should also be an essential precaution in the propagation of stock from new varieties introduced from other nurseries, which should be confined for this purpose to a quarantine house.

(*b*) *Water Supply.*

There is no evidence that a natural water supply is infected with the spores of *Verticillium cinerescens*. Lack of modern equipment and shortage of water may, however, lead to the retention of water systems that cannot be justified from the point of view of disease control. Drainage-water from houses of diseased plants should be prevented from entering surface reservoirs, and underground reservoirs, fed from streams or ditches that border the houses, should be abolished.

(*c*) *Infected Tools.*

On a nursery visited by the writer diseased areas first appeared about a year after planting the first crop on virgin soil in a newly-erected block. The fact that not a single diseased plant was observed during the first nine months after planting appears to preclude the possibility that these diseased areas arose from the planting of infected stock. Most of the diseased areas were at the edge and towards the end of the beds and enquiry elicited that the plants had been hoed and watered with tools and hoses from an adjacent block with extensive disease. The rows of wiring placed over carnation beds for the support of the plants necessitates continual laying of the hoses on the soil when watering and it seems certain that disease is frequently spread from block to block by the carrying of muddy contaminated soil on tools and hoses. The obvious remedy is to segregate the tools used for blocks that are free from disease.

SUMMARY.

(1) The diseases of the perpetual-flowering carnation generally referred to as " stem-rot " are caused by several fungi. The most important of these diseases at the present time appears to be that due to *Verticillium cinerescens. Fusarium culmorum* and other *Fusaria* considered, at the time of a previous investigation, to be primarily responsible, cause, at the present time, separate but less important diseases.

(2) It has been confirmed that the *Verticillium* disease is conveyed from crop to crop in the cuttings.

(3) There is evidence of a differential susceptibility of varieties towards different strains of *Verticillium cinerescens*.

(4) Attempts to infect the Tomato, Chrysanthemum and Aster with *Verticillium cinerescens* have failed.

(5) Control measures are discussed.

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THE USE OF BORAX IN THE CONTROL OF "INTERNAL CORK" OF APPLES

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PREFACE BY T. RIGG

PREFACE.

THE work recorded in the following papers by Messrs. Askew and Chittenden constitutes a part of a series of investigations relating to boron deficiency in New Zealand crops.

In the present paper the work concerns solely a physiological ailment of apples known as " Internal Cork ". The investigations are in continuation of the co-operative work of the Dept. of Sci. & Ind. Research and the Cawthron Institute to ascertain the cause of this ailment and to recommend practical measures for its control. " Internal Cork " has been an acute problem for a number of years to orchardists in certain parts of the Nelson District. In a previous publication of the Institute the occurrence of the ailment has been described and its association, in the severe form, with certain phases of the Moutere Hills soil and a granite soil at Umukuri has been noted.

During the 1934-35 season of the co-operative investigations it was shown that

(1) The injection of certain boron compounds into affected trees was highly beneficial in reducing the incidence of ailment.*

(2) Affected fruit, and to a less extent leaves of affected trees, had relatively low boron contents, the amounts of boron found in affected fruit being only one-third of that found in healthy fruit.†

These two results indicated clearly that "Internal Cork" of apples was caused by a deficiency of boron in the trees.

During the 1935-36 season, just concluded, an endeavour has been made to secure confirmation of this indication and to ascertain the boron status of soils, fruit and leaves under different conditions of treatment.

Particular attention has been paid to the use of borax in the control of the ailment, and the field experimental work bearing on this aspect of the problem has gone hand in hand with the chemical studies relating to the intake of boron and its distribution throughout the fruit and leaves of the trees.

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* J. D. Atkinson, *N.Z. Jour. Sci. and Tech.*, 1935, **16**, 316.

† H. O. Askew, *N.Z. Jour. Sci. and Tech.*, 1935, **17**, 388.

As a result of the investigations very valuable information has been obtained concerning the use of borax in the control of the ailment and concerning the boron status of soils, fruit and leaves of the experimental trees.

T. RIGG,
Director, Cawthron Institute.

PART I. THE INFLUENCE OF BORAX TOP DRESSING ON THE BORON STATUS OF SOIL, FRUIT AND LEAVES

By **H. O. ASKEW, E. CHITTENDEN** and **R. H. K. THOMSON**

INTRODUCTION.

In the co-operative investigations of the Dept. of Sci. & Ind. Research and the Cawthron Institute in the 1934-35 season it was shown that boron compounds were beneficial in overcoming "Internal Cork" of apples, and that affected fruit had a low boron content.

These results suggested the desirability of studying the use of borax in the control of the ailment. In the investigation three methods of using borax were studied as follows :—

(a) Borax applications broadcast around the trees,
(b) Borax solutions injected into trees, and
(c) Borax sprays of different strengths.

The importance of studying the penetration of borax into the soil, and of securing data relative to the intake of boron by the trees under the different experimental conditions was recognized, and these studies constitute the main feature of the work recorded in this paper. In order to obtain the most practical results from the investigations, the amount of "Internal Cork" under the different experimental conditions was carefully recorded.

SOIL INVESTIGATIONS.

Typical orchard areas on several soil-types were chosen for experiments in which it was desired to watch the penetration of borax used as a top dressing agent. The areas were dug over to a depth of 3-4 inches and allowed to lie for a time for settling to take place. The surface was then raked level before broadcasting the powdered borax (mixed with sand). On orchards A, D and E the borax was applied in two equal amounts on September 10th and 19th, 1935. The total applications were at the rate of either 50 pounds or 100 pounds of hydrated borax per acre. At Orchard C the whole application at the rate of 50 pounds per acre was made on September 13th. The first samples were collected immediately after the top dressing operations were completed. Further samples were obtained on October 20th, on December 6th, 1935, and on February 11th, 1936. At the later dates the depth of sampling was increased until, with the final set, the samples were taken to a depth of 18 inches. At each sampling control sets were obtained so that direct comparison could be made with the samples from the treated areas.

The boron was extracted by means of N/20 hydrochloric acid solution and estimated, after distillation with methyl alcohol, either by titration with sodium hydroxide in the presence of mannitol, or by turmeric paper under standardized conditions, according as the amounts of boron were large or small.

During the experimental period the rainfall was well distributed and was above the average for Nelson. The following data, taken at the Research Orchard, Appleby, the nearest meteorological station to most of the experimental areas, indicate that there should have been sufficient moisture in the soil to allow the borax to penetrate to lower levels.

RAINFALL AT THE RESEARCH ORCHARD, APPLEBY, 1935-36.

Period.	*Rainfall in inches.*
September 16th to October 20th, 1935	1·37
October 21st to December 8th, 1935	9·10
December 9th, 1935 to February 16th, 1936	8·98

In the first period no fall of rain exceeded 0·5 inch, but in the other two periods some very heavy falls were experienced ; on three occasions the weekly total exceeded 3 inches.

Owing to the satisfactory moisture conditions the borax penetrated relatively rapidly, as is shown by the data of Table I (page 230), where the boron content of the soil is expressed in terms of boric oxide (B_2O_3) per million parts of dry soil.

At the time the first samples were obtained some boron appears to have penetrated to the 3-6 inch layer, but this may be due to small crystals of borax falling into the core holes made during sampling, although every endeavour was made to prevent this occurring. The quantities of boron extracted from the 0-3 inch layer at the first sampling of the treated areas agree well with the amounts calculated from the rates of application. At orchards C and D, indeed, the results are somewhat high, but this may be explained by sampling errors. The data indicate that the penetration of the borax was relatively rapid, and that by the middle of February the amount of boron in the top 3 inch section was reduced to 2-4 parts of boric oxide per million of dry soil, and that the effect of the borax application could be definitely detected in the 12-18 inch section. Even in the case of the 50 pounds per acre application the penetration has been

TABLE I.

Showing Boron Contents of Soils Top Dressed with Borax.

Expressed as parts of B_2O_3 per million parts of dry soil.

Location.	Borax pounds per acre.	Depth of Sampling (inches).	Date of Sampling.				
			February 11th, 1936.*	September 19th, 1935.	October 22nd, 1935.	December 6th, 1936.	February 11th, 1936.
Orchard A	50	0–3	0·35	10·6	6·3	2·2	2·5
		3–6	0·25	1·0	0·75	1·4	1·3
		6–12	0·20	—	—	0·5	0·5
		12–18	0·15	—	—	—	0·2
	100	0–3	0·35	27·3	12·0	4·9	3·1
		3–6	0·25	1·1	1·6	1·8	1·6
		6–12	0·20	—	—	1·35	0·7
		12–18	0·15	—	—	—	0·7
Orchard C	50	0–3	0·70	22·0	9·0	4·2	4·1
		3–6	0·60	1·2	1·3	2·9	2·1
		6–12	0·40	—	—	1·0	0·7
		12–18	0·10	—	—	—	0·3
Orchard D	50	0–3	0·45	19·5	14·5	3·6	2·2
		3–6	0·30	1·4	1·3	1·5	0·9
		6–12	0·20	—	—	1·2	0·9
		12–18	0·20	—	—	—	0·3
Orchard E	50	0–3	0·50	7·5	7·0	2·5	2·1
		3–6	0·30	1·2	0·7	0·9	1·1
		6–12	0·20	—	—	0·7	0·6
		12–18	0·15	—	—	—	0·4
	100	0–3	0·50	21·0	16·3	3·4	2·2
		3–6	0·30	0·8	0·6	2·7	1·8
		6–12	0·20	—	—	1·25	0·8
		12–18	0·15	—	—	—	0·5

* Refers to untreated area; data from other sampling dates are not shown.

NOTE: Orchard A is situated on the Braeburn phase of the Moutere Hills soil type. Orchard C is situated on the Wakatu clay loam soil type. Orchard D is on the Riwaka loam soil type. Orchard E is at Umukuri on a loam overlying a coarse sand.

good. It may be remarked that on the comparatively heavy soil at orchard C the rate of penetration has been somewhat slower than on the other more sandy areas. From the reduction in the amount of borax found later in the season it appears either that some of the borax has entered into combination with soil constituents to form compounds insoluble in the dilute acid used for extraction, or that boron has been lost in the drainage water and that an approximately equilibrium condition has been reached. It is not possible at present to say which of these processes is the one acting in these experiments.

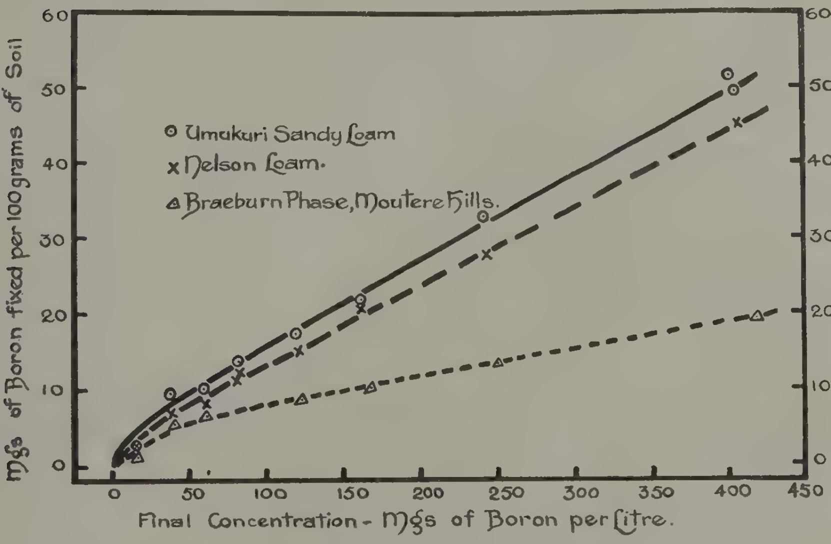

Fig. 1. Fixation of boron by soils.

That some fixation of boron occurs was shown by laboratory experiments in which soil was shaken with borax solutions (adjusted to a pH value of about 6·5). The results are shown in Fig. 1. In no case was the degree of fixation very marked, but it was sufficient to account for about 15 per cent. of the boron present, when the concentration of borax was approximately equal to a dressing of 50 pounds of borax per 3 inch acre. At higher concentrations, especially in the case of the Braeburn soil (orchard A), the amount of fixation is much less. The curves also show that the amount of fixation occurring in different soils may vary considerably with the result that the rate of penetration of borax applied as a surface dressing would be expected to vary somewhat. Rate of penetration will of course not be controlled solely by the degree of fixation.

FRUIT INVESTIGATIONS.

At orchards A and B arrangements were made to obtain samples of developing fruit throughout the growing season. At orchard A trees from an untreated area and from one receiving 100 pounds of borax per acre sown broadcast were used, while at orchard B untreated trees and trees which had received one-half pound of borax per tree were used. The varieties of apple were Jonathan at orchard A and Dougherty at orchard B. Both orchards were known to be severely affected with " internal cork " in most seasons. Sets of samples of Jonathan and Dougherty apples from the reputedly healthy Stoke area were obtained to serve as standards.

Samples were collected at fortnightly intervals, commencing on November 18th, 1935. Setting of fruit probably occurred about October 10th. Fruits were therefore about six weeks old at the time the first samples were obtained. The final samples were collected on March 9th, 1936. With each set of samples records were kept of the average weight of the apples, and of the incidence of " internal cork ". Insufficient apples were obtained in each sample to get precise data on the latter question, but the records gave general indicatory data as to the effect of the borax applications. Determinations of percentage of dry matter and of the boron content of the dry matter were made for all samples, using the whole fruits.

Further samples of fruit and leaves from all areas top dressed with borax, either by broadcast application or by local application round the trunks of the trees, were obtained at the end of the season. On these samples determinations of the boron content of the dry matter were made.

It will be convenient to consider first the detailed studies on the Jonathan and Dougherty varieties. At the outset it may be noted that the data obtained did not indicate that the borax applications had any very significant effect on the size of the fruit or of the percentage of dry matter in the fruits. In the case of orchard B (Dougherty variety) it is possible that the increase in the size of the fruit from the treated area may be significant, as other data have suggested that where the boron deficiency is most acute then the use of boron increases the size of the fruit, but that where boron deficiency is not so marked then the addition of boron to the supply of the tree does not definitely affect the size of fruit.

The data of Table II show the amounts of boron found in the dry matter of the apples at various stages during growth for the two varieties from the different orchards.

Taking first the Jonathan variety, it is seen that the boron content of the dry matter on both areas not receiving borax decreases steadily from relatively high values for the young fruits to relatively low values for the fruits at the export picking stage, and that the fruit at Braeburn (an area associated with internal cork) falls to the low figure of about 9 parts per million of boron (B) in the dry matter, whereas at Stoke (a reputedly healthy area) the lowest figure is 13·5 parts per million. On the area treated with borax, except for the first sample, the boron content of the dry matter is markedly higher than that of the untreated area, and higher even than that of the Stoke samples, at corresponding periods. It is evident therefore even by the end of November that sufficient borax had penetrated into the root zone of the trees to markedly improve the boron status of the treated trees.

Taking now the Dougherty variety, the data show that a somewhat similar type of result has been found as for the Jonathan variety. The differences between the deficient area and the treated or reputedly healthy areas are more marked than in the case of the Jonathan variety. On the deficient area the boron content has fallen to 4·1 parts per million from an initial value of 9·4 parts per million. On the healthy area the fall in boron content is much greater being from 43·9 parts to 17·6 parts per million, and on the area receiving one-half pound of borax per tree the boron content has remained relatively constant falling from a maximum value of 20·1 to 15·2 parts per million. It is to be noted that the final values for the healthy and the treated areas are approximately the same.

TABLE II.

Parts per million of Boron (B) in Dry Matter of Developing Apples.

Date.	Jonathan.			Dougherty.		
	Braeburn	(Orchard A).	Stoke.	Umukuri	(Orchard B).	Stoke.
	Untreated.	Treated.	Untreated.	Untreated.	Treated.	Untreated.
November 18th, 1935 ..	33·0	21·5	29·2	9·4	17·3	43·9
December 2nd, 1935 ..	17·8	24·0	23·0	7·2	20·1	33·0
December 16th, 1935 ..	14·1	23·3	21·5	5·9	17·3	23·7
December 30th, 1935 ..	11·7	18·3	18·1	5·1	19·4	22·0
January 13th 1936 ..	10·9	17·6	17·3	4·9	14·7	20·1
January 27th, 1936 ..	11·9	17·0	17·1	3·8	14·9	18·1
February 10th, 1936 ..	8·3	16·9	15·4	5·6	16·9	18·1
February 24th, 1936 ..	9·0	17·8	14·5	4·9	16·2	19·3
March 9th, 1936 ..	8·9	17·5	13·5	4·1	15·2	17·6

NOTE: Setting of fruit took place about October 10th, 1935.

TREATMENTS: Borax at the rate of 100 lb. per acre was broadcast at orchard A; at orchard B borax was spread around the trees at the rate of one half pound per tree.

One curious fact may be noted: this is the maximum figure shown in each case for the samples taken from the treated areas on December 2nd. This rather suggests, especially in the case of the Dougherty variety, that the trees were receiving benefit from the borax applications previous to the taking of the first samples, but had not absorbed sufficient for optimum conditions. It is clear, however, that boron found its way very soon after the areas were top dressed into the conducting systems of the trees.

Further data obtained during this investigation are shown in Table III, where the boron contents of the dry matter of leaves and of fruit (fleshy part only) are given. These cover six orchards, in four of which the broadcasting method was used, while in the other two the borax was placed in a relatively narrow band round the trees. Six varieties of apple were under experiment. On all areas the use of borax has increased markedly the boron content of the fruit ; where two rates of application were employed, the higher rate has resulted in greater amounts going into the fruit. Although the boron content in one case reached the figure of 30·6 p.p.m., no toxic symptoms on the trees were noticed.

The boron contents of the leaves suggest that the apple tree meets the requirements of the leaves for this element in the first instance and that in the case of deficiency the fruits fall in boron content long before an appreciable decline can be noticed in the boron content of the leaves.

TABLE III.

Boron Content in parts per million of Dry Matter of Leaves and Fruit from Areas Top Dressed with Borax.

Orchard.	Variety of apple.	Quantity of borax used.	Boron (B) in p.p.m. of dry matter.	
			Leaves.	Fruit.
A	Jonathan	Control.	25·4	7·7
,,	,,	50 pounds per acre.	—	10·0
,,	,,	100 pounds per acre.	25·7	16·0
B	Dougherty	Control.	12·6	3·9
,,	,,	½ pound per tree.	21·8	15·1
C	Delicious	Control.	28·1	16·6
,,	,,	50 pounds per acre.	27·0	30·4
D	Sturmer	Control.	25·1	11·2
,,	,,	50 pounds per acre.	24·4	23·3
E	Ballarat	Control.	17·5	8·9
,,	,,	50 pounds per acre.	22·1	18·1
,,	,,	100 pounds per acre.	21·3	21·0
F	Rome Beauty	Control.	25·7	6·5
,,	,,	½ pound per tree.	24·5	21·2
,,	,,	1 pound per tree.	25·8	30·6

NOTE : Borax applied on September 19th, 1935. Leaves collected February 27th, 1936, and fruit collected March 1936.

In no case could it be said that the borax applications beneficially affected the vegetative conditions of the trees, although " internal cork " was overcome.

DISCUSSION.

The data presented above leave no doubt as to the ability of boron to penetrate readily into the root zone of the apple trees even on comparatively heavy types of soil, and to find its way into the leaves and fruits. In the present experiments the aim was to get information on the penetrative power of the borax, consequently the sites chosen for the experiments were such that soil conditions might be as uniform as possible, and were chosen not for direct information as to possible effect of increased intake of boron on the incidence of " internal cork ". In fact orchard C is reputedly free from " internal cork ". Nevertheless, records have been kept in several cases of the incidence of " internal cork " on the untreated and treated areas. The use of borax has in all cases practically eliminated the ailment, although in this season the incidence of " internal cork " appears generally in the district to be much less than last year; consequently the difference between the amount of " internal cork " on treated and untreated areas is not so great as it would have been in the previous season.

Table IV.

Showing intake of Boron (B) in γ in Developing Apples.*

Date.	Jonathan.			Dougherty.		
	Braeburn (Orchard A).		Stoke.	Umukuri (Orchard B).		Stoke.
	Untreated.	Treated.	Untreated.	Untreated.	Treated.	Untreated.
November 18th, 1935 ..	25·0	11·3	14·6	4·3	7·9	15·0
December 2nd, 1935 ..	23·5	30·6	28·3	8·2	23·9	36·7
December 16th, 1935 ..	36·0	62·3	58·7	15·7	50·5	53·2
December 30th, 1935 ..	50·5	73·1	76·3	19·7	82·6	82·0
January 13th, 1936 ..	79·2	132·7	135·7	29·4	113·8	149·3
January 27th, 1936 ..	112·7	154·8	173·5	29·4	136·2	172·2
February 10th, 1936 ..	103·3	184·0	197·2	51·3	188·8	196·6
February 24th, 1936 ..	132·1	230·3	216·4	51·8	218·1	252·9
March 9th, 1936 ..	138·2	252·4	232·1	51·1	222·5	263·3

* γ equals one-millionth of one gram.

Treatment: At orchard A on the treated area borax was broadcast at the rate of 100 lb. per acre.
At orchard B the treated trees each received ½ lb. of borax spread around the tree.

It is of interest to calculate from the data obtained from the systematic sampling of the Jonathan and Dougherty varieties the total weight of boron in an average apple at the different sampling periods. This has been done, with the results shown in Table IV and plotted in Figures 2 and 3 (pages 236-7). The weight is reported in γ per apple (γ is 10^{-6} g.).

In the case of both varieties there is relatively little difference in the intake of boron between the fruit from the healthy orchards and the fruit from the borax-treated orchards. The rate of intake increases with increase in size of the fruits until towards the end of the experimental period there is a slowing down of the rate of intake. On the untreated areas the rate of intake practically falls to zero towards the end of the experimental period, especially in the case of the Dougherty variety on the very deficient area. There is a remarkable difference between the total amounts of boron in fruit from treated areas as compared with fruit from untreated areas. Thus with the Jonathan variety the intakes of boron by the treated and untreated fruits are 252·4 and 138·2 units respectively, and with the Dougherty variety the respective figures are 222·5 and 51·1 units.

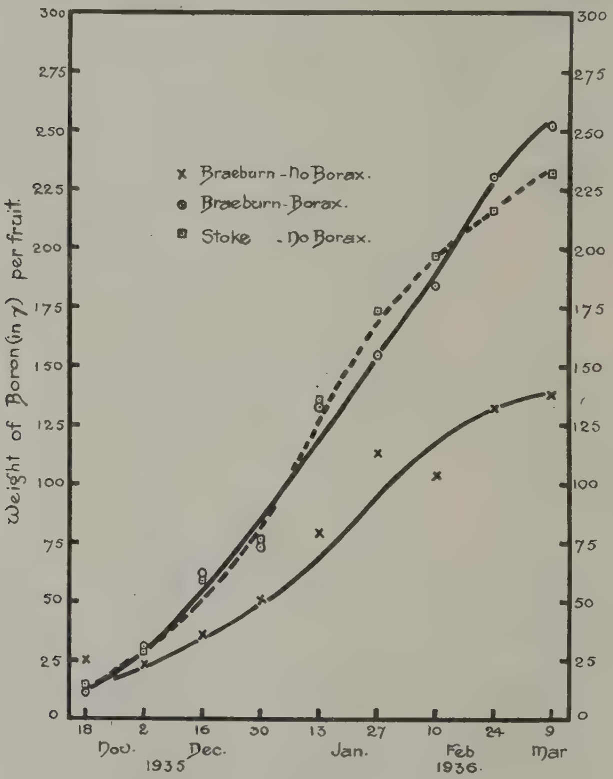

FIG. 2. Intake of boron by developing Jonathan apples, expressed in γ per fruit.

The question may be raised, in view of the small quantities of boron found in the soils and the relatively much larger amounts found in the fruit and leaves of the trees, as to what weight of boron is removed in a crop of apples. On the basis of 600 bushels of fruit per acre and a content of 3 parts per million in the fresh fruit (that is, approximately 18 parts per million on the dry basis), the amount of boron in the crop would be approximately 33 grams, or not much more than 1 ounce. Then from the leaves, on the basis of 150 trees per acre with a weight of 14 pounds of fresh leaves containing 12 parts per million of boron (that is, allowing 45 per cent. of dry matter in the fresh leaves and 27 parts per million of boron in the dry matter) the amount of boron passing into the vegetative parts of the tree (excluding new wood) would be approximately 11 grams. For the annual requirements, therefore, not less than 44 grams of boron would be required per acre. This is equivalent to 382 grams, or approximately

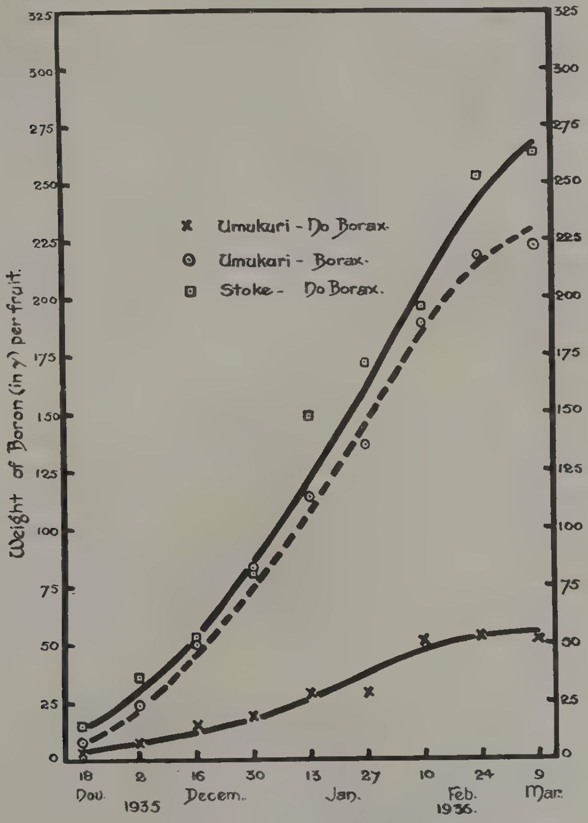

Fig. 3. Intake of boron by developing Dougherty apples, expressed in γ per fruit.

14 ounces, of hydrated borax. An application of 50 pounds of hydrated borax per acre does therefore provide very fully for the estimated requirements of apple trees for boron. Even assuming that in droughty seasons little if any boron from the natural supplies contained in the soil goes into solution, a top dressing of 50 pounds of borax per acre supplies more than fifty times the yearly requirements of the trees.

On the practical side it may be noted that in no case was any harm done to the trees by the quantities of borax used. Also it is not possible to say for how many seasons the amounts of borax employed would be effective in controlling " internal cork ". Observations should therefore be made on the treated areas for a number of years. Moreover, it is not known at present which is the most economical method to use, but it does appear from the results obtained in this season that the use of 1 pound or 1 half-pound of hydrated borax distributed round the tree, or broadcasting the borax at the rate of 50 to 100 pounds per acre, is a safe procedure to employ in the prevention of " internal cork " in apples on orchards where this ailment has been in evidence in previous seasons.*

SUMMARY.

1. Application of powdered hydrated borax by top dressing was found to rapidly increase the boron content of soils to a depth of 18 inches, thus getting boron into the root zone of apple trees.

2. The boron content of developing apples, on the dry matter basis, was determined and was found to decrease with increase in size of the fruit.

3. On areas top dressed with borax the boron content of the fruits was approximately equal to that of fruits reputedly free from " internal cork " and grown on healthy soils.

4. The use of borax had no definite effect in most cases on the size or dry matter content of the treated fruits as compared with untreated fruits.

5. Borax used in the above manner is beneficial in reducing the incidence of " internal cork " on trees previously affected with this ailment.

6. It is pointed out that the normal annual requirement per acre of an orchard for leaf and fruit growth is equivalent to only 14 ounces (approx.) of borax.

7. It is concluded that the use of 1 half-pound to 1 pound per tree, or broadcasting 50 pounds to 100 pounds per acre, of hydrated borax is safe and satisfactory for the control of " internal cork " of apples.

* It is interesting to note that Read (3) states that in Tasmania and Canada diseases similar to " internal cork " in New Zealand are responding to boron treatment.

ACKNOWLEDGMENTS.

Thanks are due to Miss E. B. Kidson for making some of the boron determinations reported in this paper, and to Mr. D. J. Stanton for much assistance in the laboratory examination of the fruit.

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(2) *H. O. Askew.* N.Z. Journ. Sci. & Tech., 1935, **17,** 388.
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PART II. THE EFFECT OF TREE INJECTION OF BORAX SOLUTIONS ON THE BORON STATUS OF APPLE TREES

By **H. O. ASKEW** and **E. CHITTENDEN**

INTRODUCTION.

The experiments reported by J. D. Atkinson (1) have shown the great value of tree injection methods for studying deficiencies of plant foods required only in small amount. It was considered that data relating to the distribution of boron in trees injected with borax solutions would be helpful in demonstrating the value of this method of supplying boron to trees affected with " internal cork ".

For the purpose of obtaining full information concerning the effect of tree injections of borax solutions on the boron status of the tree, trees from both healthy and unhealthy orchards were selected for the experiments. Samples of leaves and fruit were subjected to chemical examination and records were kept of the amount of " internal cork " on the different trees.

EXPERIMENTAL.

At Umukuri Jonathan and Delicious trees in an orchard usually badly affected by " internal cork " were treated. The Jonathan trees carried about three bushels of fruit per tree, while the Delicious trees were smaller and carried about 2·5 bushels of fruit per tree. The Delicious fruits were very small. None of the trees showed much leader growth so that composite samples of leaves had to be taken from two treatments in order to get a satisfactory sample for chemical examination. Injection was carried out on November 2nd, 1935.

One limb in each of a Jonathan and a Delicious tree at Umukuri was injected with 5 grams of borax, the remainder of the tree serving as a control. The Jonathan was a good-sized tree carrying about five bushels of fruit. The injected limb would represent about one-fourth of the tree. The Delicious tree was of average size and carried about four bushels of fruit ; about one-sixth of the tree was represented by the injected limb. In the cases of both injections the inlet-holes were about nine inches above the junction with the branch of the tree.

All the solutions were of 0·25 per cent. hydrated borax and about twenty-four hours was required for two litres of solution to be taken up. Injections into the trunk were made about nine inches below the crotch.

On the healthy orchard well-grown Jonathan trees were used for the experiments. The injections were commenced on November 12th, 1935, when all trees receiving 10 grams or less of borax were treated. The tree which was to receive 15 grams received 10 grams on November 12th and a further 5 grams the next day. In these trees the solutions were taken up at the rate of about two litres per hour. In all cases the strength of the solution injected was 0·25 per cent. hydrated borax.

In all the experiments the trees were in full leaf when the injections were made. No ill-effects on the foliage were observed in any of the above experiments. On the other hand no beneficial effects could be seen. In an observation experiment on a Jonathan tree at Wakatu 10 grams of hydrated borax were injected on November 12th. In three weeks' time a little leaf scorch was in evidence. On December 13th a further 5 grams were given and in a fortnight from then the leaf scorch had extended a little. A further 5 grams of borax was given on February 3rd, 1936, when leaf scorch became more noticeable. The total amount of leaf scorch was small, however, and the tree recovered quite well from the effects of the injections.

Data covering the chemical analyses of fruit and leaves and the incidence of " internal cork " are given in Table I. At Wakatu no examination of fruit was made, as this orchard has not given any evidence in previous seasons of the presence of " internal cork ".

As would be expected from the amount of borax injected into the trees, in all cases very material increases in the boron content of the fruits of treated trees have been found, the increases being particularly marked in those cases where only one limb of the tree was treated. It is interesting to note that, although precautions were taken to inject the borax at a good distance above the junction of the limb with the trunk of the tree, a measurable amount of boron has migrated to the untreated branches of both the Jonathan and the Delicious trees ; for example with the Jonathan tree, the content of boron of the fruits

TABLE I.

Effect of Injection of Borax on Boron Content of Leaves and Fruit and Incidence of " Internal Cork ".

Location.	Variety.	Hydrated borax grams.	Boron p.p.m. on dry basis.		"Internal cork." Per cent.
			Fruit.	Leaves.	
Umukuri (Unhealthy)	Jonathan	0	3·6	20·4	94·22
		2·5	42·7	31·7	Nil.
		5·0	41·8		Nil.
		5·0*	63·9	—	Nil.
		0	8·4	—	4·0
	Delicious	0	4·0	15·1	9·0
		2·5	17·5	33·6	Nil.
		5·0	19·2		Nil.
		5·0*	63·2	—	Nil.
		0	6·6	—	7·0
Wakatu (Healthy)	Jonathan	0	21·3	25·0	—
		2·5	27·2	30·7	—
		5·0	34·4	29·4	—
		10·0	41·0	30·5	—
		15·0	76·1	34·6	—

* One limb injected ; the following figure is the control from this tree.

from the untreated portion of the tree was 8·4 p.p.m. as compared with 3·6 p.p.m. for fruit from untreated trees. As the treated limb comprised only one-fourth to one-sixth of the trees it is apparent that the amount of boron migrating from the treated limbs was considerable. At Wakatu, a healthy area, the increases in boron content of the fruits was definite but not so striking as on the unhealthy Umukuri area. The boron content of the leaves has also been increased only to a slight extent at Wakatu but very materially at Umukuri. The two figures for treated trees at Umukuri are from composite samples taken from trees receiving 2·5 grams and 5 grams of borax ; the leafage was too scanty on these trees to obtain sufficient material for individual samples.

The injection of borax has resulted in the complete control of " internal cork " in all cases where it was carried out ; this is particularly marked with Jonathan, as there was relatively little trouble with Delicious on this orchard this season. With the former variety there has also been a definite decrease in the amount of " internal cork " on the remainder of the tree, on which only one limb was treated ; a boron content of 8·4 p.p.m. on the dry matter has accompanied a reduction in incidence of " internal cork" to 4 per cent. as compared with 94 per cent. and 22 per cent. on two untreated trees.

CONCLUSION.

The results of this experiment definitely show that injection of hydrated borax into apple trees increased the boron contents of fruits and leaves of treated trees and in all cases gave complete control of " internal cork " even with 2·5 grams of borax per tree.

The fact that migration of borax occurs is also of interest and importance not only for the present purpose but also from the point of view of injection technique with ordinary fertilizing salts.

ACKNOWLEDGMENT.

Thanks are due to Mr. D. J. Stanton for assistance in the preparation of the samples for chemical examination.

REFERENCE.

(1) *J. D. Atkinson.* N.Z. Journ. Sci. & Tech., 1935, **16,** 316.

PART III. EFFECT OF BORAX SPRAYS ON THE BORON STATUS OF FRUIT AND INCIDENCE OF "INTERNAL CORK" IN APPLES

By H. O. ASKEW and E. CHITTENDEN

INTRODUCTION.

Experiments in California have shown the value of zinc salts in the control of " die-back " in certain prune orchards, and it was also known that nitrate of soda sprays were in common use in Tasmania and that beneficial results from this method of supplying soluble nitrogen were obtained. It was considered that a similar procedure using borax solutions might prove effective in supplying boron in the case of trees affected with " internal cork ". The experiments recorded in this section were instituted therefore to ascertain the effect of borax sprays on the boron status of fruit and leaves and on the incidence of " internal cork ".

EXPERIMENTAL.

Preliminary trials having shown that borax solutions up to a strength of one per cent. of hydrated borax had no deleterious effect on the foliage of apple trees it was decided to use three strengths of borax spray, namely 0·1 per cent., 0·5 per cent. and 1·0 per cent. in an orchard at Umukuri, badly affected with

" internal cork ". In another series of experiments hydrated lime equal to three-eighths the weight of the borax was added to render most of the boron insoluble. In these trials the spray was applied at the rate of 1 gallon per tree ; in most cases only half the tree was sprayed, the other half being left as a control. Two trees were used at each concentration of spray, except that a separate set of six trees was sprayed all over with 1 per cent. spray. For this last experiment control trees were chosen for examination of fruit at the desired time. The spray was applied on November 21st, 1935.

Samples of fruit were collected on March 10th, 1936, for chemical analysis and for examination of the incidence of " internal cork ". The results are shown in Table I.

TABLE I.

Boron Content and Incidence of " Internal Cork " from Trees sprayed with Borax Solution.

Treatment.	Lime added.	Boron p.p.m. on dry basis.	" Internal cork." Per cent.
Borax solution 1·0% ..	No	40·4	Nil.
Unsprayed half of tree ..	No	8·4	Nil.
Borax solution 0·5% ..	No	25·1	Nil.
Unsprayed half of tree ..	No	7·9	20, nil.
Borax solution 0·1% ..	No	12·7	Nil.
Unsprayed half of tree ..	No	6·2	69, 75.
General control	—	3·6	100, 66, 98.
Borax solution 1·0% ..	Yes	26·2	Nil.
Unsprayed half of tree ..	Yes	6·9	16
Borax solution 0·5% ..	Yes	23·4	Nil.
Unsprayed half of tree ..	Yes	7·4	7
Borax solution 0·1% ..	Yes	11·9	Nil.
Unsprayed half of tree ..	Yes	7·5	13
General control	—	4·9	62, 38.

In the borax without lime experiments 100 apples were collected from each side of all trees so that comparison could be made of the incidence of " internal cork ". For chemical analysis a composite sample of the fruit from the two trees of each treatment was obtained. In the borax plus lime series a composite sample of fruits from each treatment was used both for incidence of " internal cork " and for chemical examination.

From the percentages of " internal cork " shown by the general control trees it is clear that the ailment was severe on many trees in this orchard. But the data of Table I indicate quite definitely that in all cases, whether lime was used or not, control of " internal cork " has been obtained even with a spray as weak as 0·1 per cent.

A spray trial not mentioned in Table I was carried out in which the whole of six trees were treated with the 1 per cent. spray, when complete control of "internal cork" was also obtained. These six trees were strictly comparable with the five general control trees given in Table I. In this trial the boron content of the fruit was raised to 52·1 p.p.m. on the dry basis, as compared with 3·6 p.p.m. and 4·9 p.p.m. for the samples from the control trees. The boron contents of all the fruits from the sprayed trees have been increased very materially over those shown by the general controls. This statement applies even to the unsprayed halves of the trees. Migration of borax therefore, particularly in the cases where lime was not used, took place from the leaves of the sprayed halves of the trees to the unsprayed halves to a degree sufficient to definitely increase the boron contents of the fruits on the unsprayed halves and to increase them to sufficiently high values so that in several cases no "internal cork" was found in those fruits. In other cases, particularly when lime was used, the amount of boron which migrated to the unsprayed halves was not sufficient to prevent, but, sufficient to reduce, the incidence of "internal cork". Migration of boron was also found to take place when one limb of a tree was injected with borax in some previous experiments.

Inquiry may be made as to what proportion of the borax spray remains in the leaves. It is obvious that a proportion must be lost through leaching by rain, a proportion will be translocated and a proportion may remain in the leaves as a species of "luxury" concentration. Only one sample of leaves has been available and that one came from trees sprayed with the 1 per cent. solution. The boron content was found to be only 27·2 p.p.m. for a sample taken on February 27th, 1936; this may be compared with the value 20·4 p.p.m. for a sample from untreated Jonathan trees in the same orchard. Although an increased boron content is evident in the sample from the sprayed trees, yet it is not very high, as a content of about 25 p.p.m. on the dry basis may be considered a normal figure for leaves from healthy trees. This would indicate that, if there is any "luxury" concentration of boron in the leaves, it is reduced to a normal figure later in the season.

CONCLUSION.

The results of this experiment definitely show spraying with borax solutions is a practicable method of controlling "internal cork" of apples. Even if the 1 per cent. spray were adopted and 1 gallon given to each tree then only 15 pounds of hydrated borax would be required per acre. But judging from the chemical data a spray of 0·50 per cent. borax should provide the full requirements of the trees for boron.

In view of the fact that absorption of boron is dependent on the retention of the borax sprays on the leaves for some time, it is probable that in commercial orchard practice two sprays of 0·25 per cent. borax in November, separated by an interval of twenty days, would be the safest procedure to ensure that the full requirements for boron were met.

From preliminary trials conducted at the Institute there does not appear to be any objection to introducing the borax into the lime-sulphur sprays used by orchardists during this period of the year. Further work on this point is, however, desirable before its adoption as a routine procedure.

SUMMARY.

1. The use of sprays consisting of hydrated borax in aqueous solution with or without the addition of hydrated lime controlled " internal cork " of apples.

2. Migration of borax occurred from the sprayed to the unsprayed halves of the trees.

3. It is suggested that two applications in November of a 0·25 per cent. borax spray would be satisfactory for orchard use.

ACKNOWLEDGMENT.

The assistance of Mr. D. J. Stanton in the preparation of the samples for chemical examination is gratefully acknowledged.

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THE NORTHERN SPY AS A ROOTSTOCK WHEN COMPARED WITH OTHER STANDARDIZED EUROPEAN ROOTSTOCKS*

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PART I. REFERENCES IN LITERATURE

Northern Spy is an apple variety not only grown for its fruit but also used as a rootstock, on account of its immunity from attack by Woolly Aphis (*Eriosoma lanigerum* Hausmann). In countries such as New Zealand, Australia and South Africa, where Woolly Aphis is a serious pest and establishes itself on the roots of the apple tree, Northern Spy has been used in the last twenty-five years almost exclusively as a rootstock. In South Africa it is illegal to import rootstocks which are not immune to this pest. Until recently Northern Spy was the only well-known immune rootstock, though Winter Majetin and Ivory's Double Vigour have been used on a small scale commercially.

ORIGIN AND DISTRIBUTION.

The fullest description of Northern Spy appears to be given by Beach (1) in 1905; he says that it " originated in a seedling orchard of East Bloomfield, New York. This orchard was planted by Herman Chapin with seedling trees grown from seeds brought from Salisbury, Connecticut about 1800. Sprouts from the original tree were taken up and planted by Roswell Humphrey who raised the first fruit." It was not distributed outside the Bloomfield area till after 1840. It is listed in 1845, by Downing (2) in New York State as a promising variety. By 1857 Hogg (3) was listing it in England as a new promising variety from America of the Spitzenburgh family. In 1852 (4) it was advocated as a good variety for certain localities. Hogg (5) mentioned it again in 1860. In 1883 a sample of Northern Spy apples was exhibited in England at the National Apple Congress at Chiswick by F. G. Wilson, Esq., F.R.S., " Heatherbank ", Weybridge Heath, Surrey (6). The fruit had been grown in an orchard house.

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* Parts of a Thesis approved for the Degree of Doctor of Philosophy in the University of London.

IMMUNITY TO WOOLLY APHIS.

Curiously enough none of these pomologists mention the characteristic of Northern Spy which has since caused its distribution to be so widespread—i.e., its immunity from Woolly Aphis. Yet in 1909 Theobald (7) takes this for granted and cites French (8) and Lounsbury (9) for referring to this characteristic in 1896 when it had already been introduced on this account as a rootstock into Australia (Victoria), and the Cape of Good Hope. French (10) gives a most interesting account of how " the first systematic experiments with the non-blighting stock, the 'Majetin' (which) were carried out by Messrs. T. Lang & Co., the well-known nurserymen of Melbourne and Ballarat in 1868-70, their attention having been drawn to this apple in 1862, and to the descriptions thereof, given by Geo. Lindley in his *Guide to the Orchard* " ; he goes on to say that " the variety called ' Northern Spy ' was raised in America, and was also introduced here by Messrs. Thos. Lang & Co., and but little else is now used on which to work young trees of the apple." Whilst the reference in Lindley shows how Majetin was found to be immune to Woolly Aphis by orchard observation, no similar reference is quoted to show when and how attention was first drawn to the same fact about Northern Spy.

Lounsbury (9) in 1897 says that blight proof stocks were first employed in Australia and " are said to have come into very general use ". He adds that " the use of blight proof stocks has been agitated by the Department of Agriculture of this Colony, and young trees on such stocks may now be purchased of several Colonial nurserymen. The supply of these trees at present available is, however, very limited " and that, as they cost more to raise than trees on seedlings, a higher price should be charged.

The importation of these stocks into South Africa was specifically allowed by the Agricultural Pests Act of 1911 (11). In 1913 Southern Rhodesia incorporated a similar clause into their " Importation of Plants " Regulation Ordinances No. 20 (12). Again, Cole (13) in 1911 says that Northern Spy's main recommendation is its resistance to Woolly Aphis but states that it does not pass on this property to the scion worked upon it. He also says (13) that it is because of this characteristic that it is necessary to work a piece of Northern Spy stem on to the original Northern Spy piece root so as to prevent the scion from rooting as it would do if worked directly upon a piece of Northern Spy root.

In 1930, J. M. Ward (14) in his survey of the development of fruit growing in Australia, says that Northern Spy was coming into use as a rootstock immune to Woolly Aphis in that country as far back as 1890. It seems clear then that its reputation for immunity to Woolly Aphis must have been pretty conclusively established before the end of the nineteenth century, though the writer has been unable to trace any more specific record. It is also clear that its widespread distribution outside America was primarily as a rootstock rather than as a fruiting variety.

The first critical tests appear to be those of Staniland (15) in 1923, when he established the fact that Northern Spy was immune to attacks by Woolly Aphis both above and below ground in England. In 1927 Le Pelley (16) confirmed this finding and states that Northern Spy is " immune " for all practical purposes ; he says that colonies of Woolly Aphis will live on Northern Spy but that such colonies are weak and do not reproduce. He also tested the " resistance " of some seedlings raised at the John Innes Institution from Northern Spy crossed with " Doucin " (Malling No. II). The latter is not resistant to Woolly Aphis. He showed by his tests that resistance to Woolly Aphis was a heritable character. Further by actual experiment he arrived at the same conclusion as Cole (13) that this immune rootstock did not pass on its immunity to the scion. Conversely Fluke (17) in 1930 says " the use of a resistant scion such as Northern Spy does not influence the susceptibility of the stock ". Davy (18) also notes that there were trees of Northern Spy used as a variety in South Africa which are grafted on " Boer " apple stocks. The tops of these trees are vigorous and bear well but the roots are covered with Woolly Aphis. He concludes that the root form of this disease is possibly not so important as has been supposed.

Yerkes (19) also notes that seedlings of Northern Spy are being used in rootstock trials with seedling crab stock with the idea of obtaining many trees resistant to Woolly Aphis. Vegetatively propagated Northern Spy is now accepted as immune to the attacks of this pest all over the world.

IMMUNITY TO OTHER PESTS.

Beach (1) in his account of Northern Spy in New York notes it as a variety particularly susceptible to scab. In 1928 Vincent and Luce (20), state that it is somewhat resistant to Collar Rot in Washington, and in the same year Fromme (21) notes that Northern Spy shows some resistance to Black Rot disease in Virginia. In 1929 Childs (22) from Oregon notes that Northern Spy is free from Canker and says that this may be due to immunity from aphis attack or immunity from the disease. Hatton (23) on the other hand, records that, under East Malling conditions, Spy is very susceptible to Powdery Mildew (*podosphaera leucotricha*).

BEHAVIOUR AS A ROOTSTOCK.

VEGETATIVE PROPAGATION.

A detailed account of the vegetative propagation of Northern Spy is given in 1911 when Cole (13) in Australia describes a method of obtaining trees on this rootstock. A piece of Northern Spy root is taken and on to it is grafted a piece of Northern Spy stem. This is allowed to grow for one year and then budded with a scion variety. This method, previously described by Lounsbury (9) in 1897 mentioned by Davey (24) in Australia 1929 and also in a pamphlet published by the Union of South Africa (25) in 1923. Cole (13) also described the conditions and precautions necessary to get Northern Spy to root well on stool and layer beds, and says that cooler and moister districts are best adapted to the raising of Northern Spy by these methods. Woodhead (26) gives a description of similar methods which have been found to be successful in New Zealand. He also reports (27) in 1933 that Northern Spy, when grown from root cuttings, developed a deeper root system and was more vigorous as a rootstock than when grown from layers. Knight and others (28) obtained practically no rooting of Northern Spy from stools in England and say that it does not readily root in the early years when layered. C. G. Savage (29) says that Northern Spy " is easily propagated and roots readily in New South Wales ". He does not mention the method of propagation in use but probably means the piece root grafting method described by Cole (13).

The evolution of this cumbersome method of working a piece of Northern Spy root with a piece of Northern Spy stem and then budding with the required scion variety a year later is evidence that Northern Spy is difficult to propagate vegetatively and requires special methods.

IN THE ORCHARD.

Australia.

French (10) speaks of it as a better immune rootstock than Winter Majetin in Victoria.

In 1929 Davey (24) writing of Victorian conditions says, "Apples on seedling stocks develop more vigorous trees and usually rapidly outgrow those on roots of stocks from ' blight proof ' trees. Apples on selected Northern Spy roots generally make better trees than those worked on growths taken from Northern Spy stools."

Savage (29) 1930, writing of conditions in New South Wales says " the great majority of apple trees have been worked on Northern Spy. . . . There are strains of Northern Spy. The question of suitability of Spy stock for various types of soils and varying climatic conditions or compatibility . . . has never been seriously considered." Ward (14) 1930, after writing of the adoption of Northern Spy as a rootstock in Australia says " years later a number of orchardists became dissatisfied with the growth and production of these trees . . ".

Barnard and Read (30) 1932, note that when strong growth of apple trees on Northern Spy is found it is associated with good cropping. Fowler (31) in 1934 records that a quantity of selected Northern Spy material is being worked up for experimental purposes in South Australia. Quinn (32) 1935, in South Australia reports that Northern Spy has proved to be a better rootstock than Winter Majetin or Cole's Paradise in their experimental orchards. Hence the position in Australia seems to be that Northern Spy is the most commonly used rootstock but that it is not giving universal satisfaction.

New Zealand.

Cutler (33) 1930, says " regarding Northern Spy—the stock generally used in New Zealand—this variety is admitted to be the best we have (it is always grown vegetatively), but we also know that there are several varieties that are not quite at home on it, especially on some soils."

Allan and Woodhead (34) in 1933 published the results of investigations into the different strains of Northern Spy found in New Zealand. They had isolated nine types on botanical characters but found that great variation in growth and production was to be found among trees all on stocks of the same botanical characters. They produce evidence that Northern Spy is not a suitable stock for all varieties under all conditions. They note that trees on seedling stocks and on Ivory's Double Vigour produce more vigorous trees which come into cropping later than trees on Northern Spy. They also say that " seedlings are usually deep rooting and well furnished with fibrous roots whereas Northern Spy has a shallow and comparatively coarse root system ". This work is summarized in the Annual Report of the D.S.I.R. (35).

South Africa.

Davis (18) in his book *Fruit Growing in South Africa,* says that Northern Spy has been used very largely as a rootstock because of its immunity to Woolly Aphis, but that it is too dwarfing and that the root systems are weak and lack foraging power.

U.S.A.

Beach (1) mentions its use as a stock upon which less vigorous, less hardy or less healthy varieties were top worked in U.S.A., but he does not specifically mention that it was used as an immune stock in the nursery.

Yerkes (19) has compiled a summary of the rootstock work in progress in the United States. This shows that Northern Spy is under test either as vegetatively propagated material or as seedling material at experimental stations in ten States.

Tukey (36) in his account of the Northern Spy seedling U.S.D.A. 227, selected by Yerkes for its promise as a rootstock and because of its immunity, states that it has been found to be incompatible with McIntosh and Delicious but compatible with Baldwin and Spy Macoun, and shows that compatibility in this case is not connected with chromosome content.

England.

Theobald (7) in 1909, after stating that in Australia, New Zealand and South Africa it is found that trees worked on Northern Spy and Majetin stocks do not suffer from the ground form of Woolly Aphis and that these are now solely used for this purpose, emphasizes the importance of trying out these rootstocks in this country. He (37) discusses this proposition still further in 1921 and says, " It is now so well known that it need scarcely be repeated that apples grown on the Northern Spy are immune against this root form in particular, and the same is found of the Winter Majetin. The disease may, of course, occur now and again from infection from the Elm above ground, but it is doubtful if the root form can exist at all.

" It is equally certain that Paradise stock is attacked worse than anything, whilst the Crab, as one would expect, runs it very close. Until immune stock is found and all Woolly Aphis destroyed on the Apple whilst *away* from the Elm, this pest is sure to occur again and again, however well we spray our trees." And again, " Investigation into *all* immune or blight-proof stock in our Colonies and in America should be instituted. It is said the Northern Spy is no use in this country as an apple, but as stock there is no reason why it should not be employed, in spite of certain retarding features.

" Until we have some stock which will not carry the root form the pest will continue in this country, now and then breaking out into serious general or local epidemics."

It was just about this time that the testing of Northern Spy as a rootstock and the breeding of new immune seedlings was inaugurated at East Malling Research Station and the John Innes Horticultural Institution in collaboration.

By 1927 the testing had proceeded sufficiently far to justify the issue of a progress report. Hatton (23) sums up the performance of Northern Spy at East Malling by saying that it would be classed as a semi-dwarfing rootstock of the Doucin (Malling No. II) Group, but comparing unfavourably with II in early cropping and vigour. The writer hopes in a future report of this series to deal with the further development of this field experiment. Meanwhile, from the above review, it will be obvious that it is fairly generally realized that Northern Spy is not an universally satisfactory rootstock and that a comparison of its characteristics and performance with those of other rootstocks was called for. During the past two and a half years, the writer has made an intensive study of this rootstock from several different aspects, some of which afforded sufficiently suggestive data to warrant publication.

PART II. COMPARATIVE STUDIES OF ITS ROOT-SYSTEM

INTRODUCTION.

From the evidence of the literature and commentators it appears that although Northern Spy is widely used as a rootstock it is not giving universal satisfaction. Most of the commentators lay stress on the fact that in some localities it is satisfactory and in some it is not, i.e. it does not adapt itself readily to uncongenial situations. When it fails to give satisfaction the general opinion is that this is due to a poorly developed shallow root-system which involves poor anchorage and a great susceptibility to drought conditions. Under these circumstances an investigation of the root-system of Northern Spy seemed of the first importance.

METHODS OF EXCAVATION.

Skeleton and Block Methods.

There are two methods which have been used for investigating the spread, depth and general habit of root-systems. These are described by Rogers (38) as the " skeleton " method and the " block " method.

The " skeleton " method of excavating trees is used when a general idea of the conformation of the root-system is required. The root-system is not destroyed and, with the aid of the map which is made during the excavation, the root-systems can be reconstructed with the roots in the same positions as they originally occupied in the soil. The root maps made during the excavation provide a horizontal projection of the root-system. The ground is first pegged out in ½ metre squares and a trench is sunk at one edge of the marked-out ground beyond the point to which the roots of the tree to be excavated extend. The soil is then removed carefully from the vertical face of the trench in ½ metre sections. As the roots are exposed, their position is drawn and their depth from the surface noted upon a map. This map thus provides a scale drawing of the spread of the roots combined with an indication of the depth of the roots at definite points by means of " contour figures ". A root descending vertically is indicated by a small circle on the map. The figure beside the circle shows the depth of the lower extremity.

The " block " method of excavation is used when a quantitative as well as qualitative measure of the distribution of the roots of a tree is required. The ground is pegged out in ½ metre squares as before. The soil is then removed in ½ metre cubes. The top ½ metre cube is divided horizontally into three; the top two blocks being half a metre square by 17 cm. deep and the third block ½ metre square by 16 cm. deep. As each block of earth is removed the roots are drawn on the root map and their depth noted by " contour figures ". The roots are cut off at the boundaries of each block, put into a labelled paper bag and placed in a tin to prevent drying. The roots are then taken to the laboratory, washed and put into three grades according to their diameter :—(1) Fine, 1 mm. and under; (2) Medium, over 1 mm. and up to 3 mm.; (3) Coarse, over 3 mm. The roots from each grade, depth and position are weighed separately. This gives a quantitative and qualitative measure by weight of the vertical and horizontal distribution of the roots, but the root-system is destroyed and its form cannot be studied out of the soil as when the "skeleton" method is used.

IDENTIFICATION OF NORTHERN SPY MATERIAL.

The writer was given facilities to apply these methods to certain material which was available at East Malling Research Station. Although the Northern Spy has never been used extensively as a rootstock in England nor has it been grown successfully for its fruit, East Malling obtained Northern Spy from Messrs. Stuart Low of Enfield, Middlesex, among its collection of rootstocks as far back as 1912. Unfortunately the origin of this stock is not now remembered for certain, though it is believed that the firm obtained it from New Zealand. Since the variety did not adapt itself readily to vegetative propagation by the ordinary "stooling" methods used for "paradise" apple stocks, it was not included in the main apple rootstock trials at the Station. However, a small supply of it was worked up by layering for use in a subsidiary trial on which a progress report has already appeared (23) and it was this same selection of Spy that has been used in the more recent breeding and testing for immunity work. This same clone was also used to obtain scions to bud upon No. IX rootstock in an attempt to bring this variety into early bearing. It had never been questioned that this was identical with the Northern Spy grown in parts of America for its fruit and used in the various Dominions as a rootstock. It is certain that the general habit of growth and character of fruit are typical of the American variety. It is also certain that it is a selection immune to Woolly Aphis.

Allan and Woodhead, however, have more recently pointed out (34) that there appear to be a number of different types of Northern Spy stocks in circulation in New Zealand. It was therefore desirable to try and identify the East Malling selection, and other similar material which had been collected at the Station with one of these New Zealand types. Judging from leaf character as figured by Allan and Woodhead (34) and the descriptions given, the East Malling clone might equally well be their Type I or V. Other material sent from New Zealand for identification seemed to be mainly identical with the East Malling variety. The descriptions given of Northern Spy by Beach, and

Allan and Woodhead are here compared in Table I (page 255) with the hitherto unpublished description originally made of the East Malling variety by Amos, Hatton and Wellington. However, the question of variation in Northern Spy stocks was kept in view and one small experiment made for the purpose of trying to see what variation there might be in root-systems as well as in growth and foliage characters.

VARIATION AMONGST NORTHERN SPY ROOTSTOCKS.

It so happened that 13 plants had been sent to East Malling in June 1931 by an Auckland grower who suspected that he might have some " sport " types. It was claimed that this strain of Spy had been propagated from root cuttings for over forty years, and these specimens appeared to have been raised by this method. During the summer after they were planted it was recorded that five plants made poor growth, but that the remainder were more vigorous and appeared to be similar to the East Malling clonal plants of Northern Spy. This identification was checked and confirmed subsequently.

These plants afforded some material upon which to study the variability of the root-systems and since the trees were in any case to be lifted carefully for the purpose of taking root cuttings, the opportunity was taken to place them in their two groups and photograph them in December 1934. Four of the surviving trees had made poor growth and their root-systems proved to have developed as poorly as the tops. These trees are shown in Fig. 1. Fig. 2 shows a representative group of the trees which had made fairly vigorous growth. Their root-systems are as vigorous as their tops and show a marked tendency to form deep roots. The photographs suggest that these might represent different strains of Northern Spy.

Woodhead (27) illustrates two types of Northern Spy root-systems which appear to correspond very closely with those shown in Figs. 1 and 2, and says that the differences are due to the method of propagation used. In the present instance both the types appear to have been raised from root cuttings.

On the other hand it is interesting to compare the more vigorous group of these plants from root cuttings with the shallow root-systems of Northern Spy hereafter to be described, which were almost certainly produced from layers.

PRELIMINARY EXCAVATION OF UNWORKED ROOTSTOCKS.

The skeleton method was used for the preliminary investigations as the available material was very limited and not always strictly comparable.

MATERIAL.

The root-systems produced by Northern Spy, Ivory's Double Vigour (a rootstock used in New Zealand for its vigour and immunity to attack by Woolly

TABLE I.

Description of Northern Spy "Types".

	East Malling—Northern Spy Type Plant.*	Palmerston North Type I.† Northern Spy.	Palmerston North Type V. Northern Spy.	Beach's U.S.A. Northern Spy.
SUMMER. Habit	Strong—sometimes "feathered".	Strong and vigorous.	Exceptionally strong and vigorous —straight—free from branches.	Vigorous, moderately stout—slender laterals.
Leaves	Large—ovate to eliptical—(8·6 × 5·2 cm.), (concave).	Larger than any other type except V.	Large—broad—very concave.	
Pose	Horizontal to slightly drooping.	Standing away horizontally from stem.	Horizontal to slightly drooping pose.	
Apex	Apex gradually acute—slightly bent downwards at apex (recurved).	Curving downwards at apex.	With prolonged point.	
Surface	Dark green—very shiny on top—whitish dull very hairy below.		Dark green and glossy.	
Petiole	Reddish—furrow well marked.			
Stipules	Large entire ⅓-½ length of petiole lanceolate.			
WINTER. Wood	Reddish purple to light brown purple, dull, much grey pubescence. Sometimes branching rather than "feathered".			Dark brownish red mingled olive green—heavily pubescent.
Lenticels	Numerous—small, mostly round, light yellow.			Numerous, small, roundish or oblong —conspicuous, slightly raised.
Buds	Triangular, obtuse, brownish red, small, very hairy, very closely adpressed, large leaf scar.			Broad, obtuse, medium to small, slightly pubescent, adpressed, deeply set in bark.

* Fruiting trees of this clone appear identical with the American Variety.
† Fruiting trees in Aukland N.Z. are all of this type.

Aphis), and some trees of East Malling No. IX were studied. The trees of No. IX, although they were one year younger than the other trees, were used in the comparison, both because they were growing in nursery rows adjacent to the trees of Northern Spy and Ivory's Double Vigour, and also because the general habit of a No. IX root-system was known. The roots of No. IX have been found to penetrate to the rock at a depth of 9 ft. 9 in. at ten years old when growing in Malling loam (38).

The trees of Northern Spy and Ivory's Double Vigour had originally been sent from Christchurch, New Zealand, for identification and had been planted in nursery rows about one foot apart at East Malling in July 1931. The Northern Spy trees were believed to be identical with the East Malling clone. When excavated in March 1934, they were about four years old. The adjacent specimens of No. IX, which came from Holland, were planted in 1932 and were only three years old when excavated.

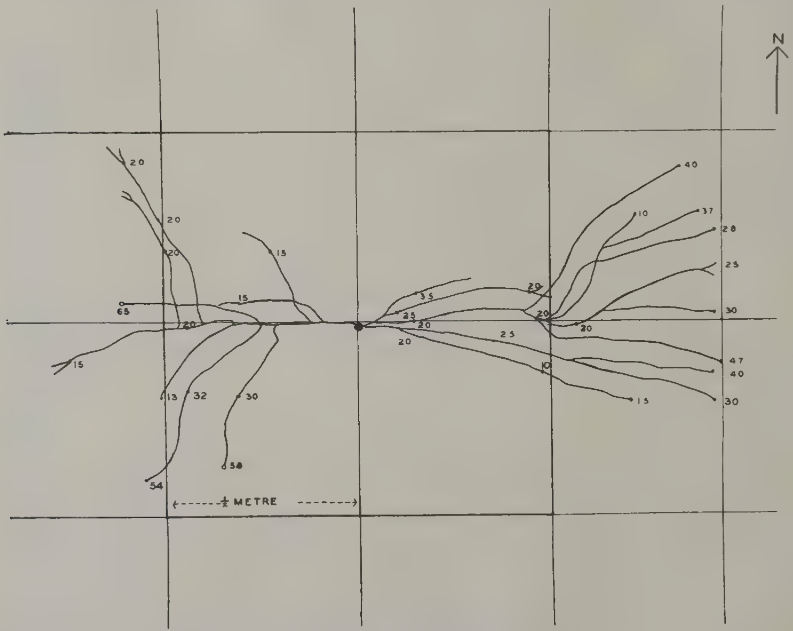


FIG. 6. Map showing horizontal projection of root-system of four-year-old Northern Spy. From this the reconstruction shown in Fig. 2 was made.

The trees of Ivory's Double Vigour were larger and more vigorous than those of Northern Spy. This is reflected in their height, Ivory's Double Vigour

1·7 metres, Northern Spy 1·2 metres. The trees of No. IX were smaller still, being approximately 1 metre high.

Soil.

The soil was a typical Malling loam of the brick earth series. The depth of the " hassock ", uncemented Ragstone material, which was found by making borings, varied from 3 to 5 feet from the surface in this area.

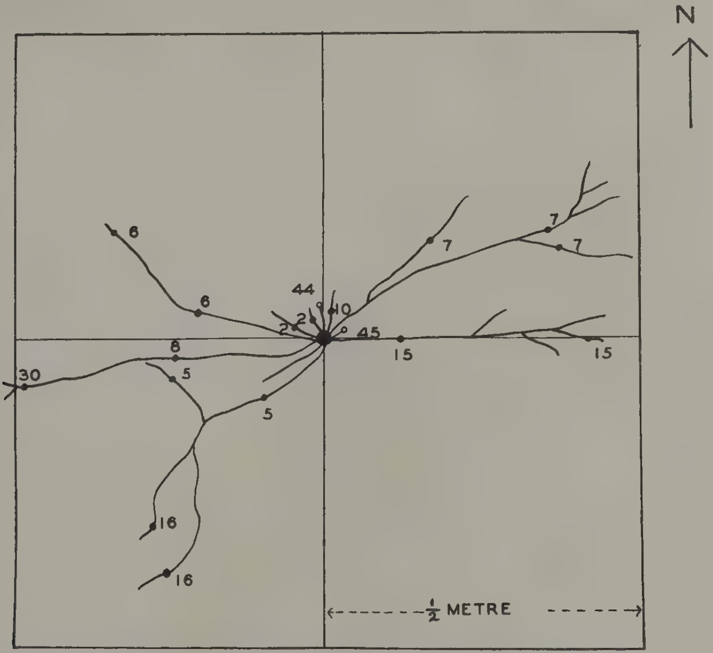


Fig. 7. Horizontal projection of root-system of three-year-old No. IX. From this the reconstruction shown in Fig. 4 was made.

Observations and Records.

Four specimens of each rootstock were excavated by the skeleton method and Figs. 3, 4, 5 show photographs, and Figs. 6, 7, 8, typical maps giving detailed pictures of these root-systems. The spread of the root-systems of Northern Spy and Ivory's Double Vigour were both about 160 cm., as can be seen from the root maps, but the roots of No. IX do not spread beyond 1 metre. The root-systems of the Northern Spy trees were inclined to be one-sided, as illustrated in Figs. 3 and 6. It can be seen from the root maps that although the roots of the trees on Northern Spy spread as far as those of Ivory's Double Vigour they did not occupy the soil to nearly the same extent. The effect of root competition (they were planted in nursery rows 1 foot apart, the rows running north and south) is also very evident in the horizontal distribution of the roots (Fig. 6). There were few deep roots on the Northern Spy trees and these were usually produced as branches from horizontal roots (as in Fig. 3), i.e., they occurred towards the periphery of the root-system. This is also illustrated by the root map (Fig. 6). Comparatively few deep roots were produced by these Spy trees but when such roots were found they were sometimes at least as deep as upon the other stocks. Indeed, the only root that penetrated to the depth of 1 metre was found on a Northern Spy tree, though some of the roots on Ivory's Double Vigour reached almost to this depth.

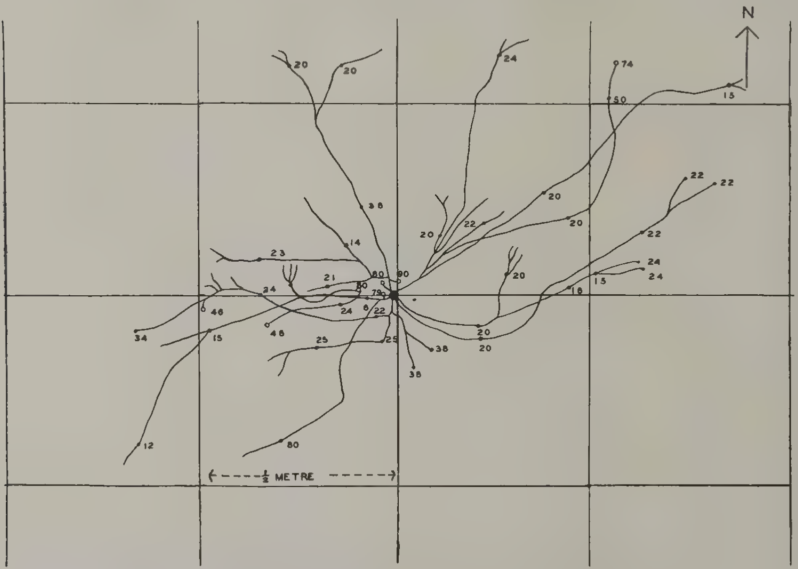


FIG. 8. Hortizontal projection of root-system of four-year-old Ivory's Double Vigour. From this the reconstruction shown in Fig. 3 was made.

The root systems of Ivory's Double Vigour were not so one-sided as those of the Northern Spy trees, and they occupied the soil more fully (see Figs. 5 and 8). The roots were either horizontal or vertical, i.e. a root did not grow out horizontally for about a metre and then turn and grow downwards (as was so characteristic with Northern Spy). Consequently trees of Ivory's Double Vigour have their deep roots more directly under the trunk of the tree and not at the periphery of the root-system. This is well illustrated in the root map, Fig. 8.

The roots of Ivory's Double Vigour were very much more fibrous than those of Northern Spy.

The root-systems (like the tops of the trees) of No. IX, which were at least a year younger, were much smaller than those of the other two stocks. They had neither the horizontal spread nor the depth of the other types of root-system, but the deep roots produced were under the trunk of the tree. This can be seen from the root map (Fig. 7). The fine, rather fibrous nature of the root-systems of these No. IX trees is illustrated in Fig. 4.

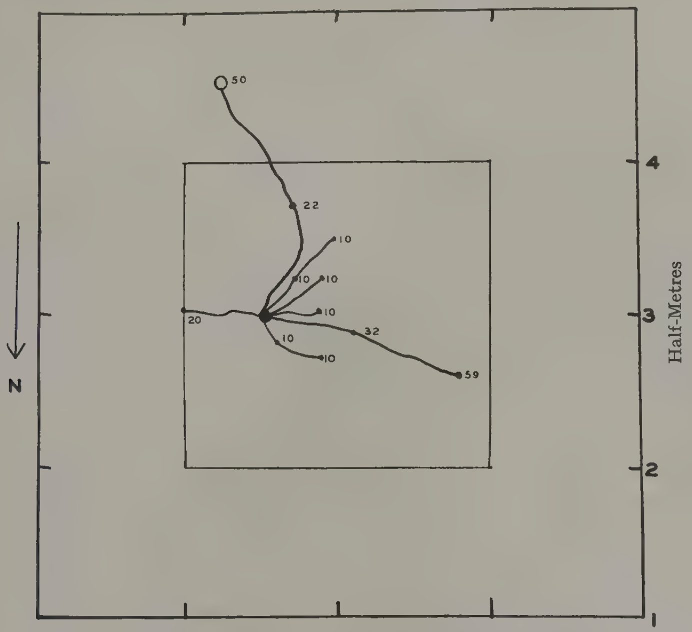


Fig. 10. Root plan of the two-year-old root-system of a layer of Northern Spy from which the reconstruction shown in Fig. 9 was made.

EXCAVATION OF CLONAL MATERIAL.

In February 1934, a plot of special clonal material was planted for future excavation. From this, a comparison of the habit of the root-systems produced in two years by unworked layers of Northern Spy and of East Malling Nos. IV and I has been made. No. IV was used in the comparison because of its supposed tendency to shallow rooting and No. I because it was expected to offer a good contrast.

MATERIAL.

Nine rootstocks of each type were used. The Northern Spy rootstocks were taken from a layer bed. They were the best rooted stocks available, but were not up to commercial first grade material (i.e. not less than $\frac{1}{4}$ inch diameter at the base) since it was found that such first grade shoots were not sufficiently well rooted for planting out. The stocks of East Malling Nos. I and IV were obtained from stools and were commercially well grown and rooted first grade. Material more comparable with that of the Northern Spy was not available, owing to the varietal differences of the young shoots in growth and rooting in which they were definitely superior to the Northern Spy. This was unfortunately unavoidable.

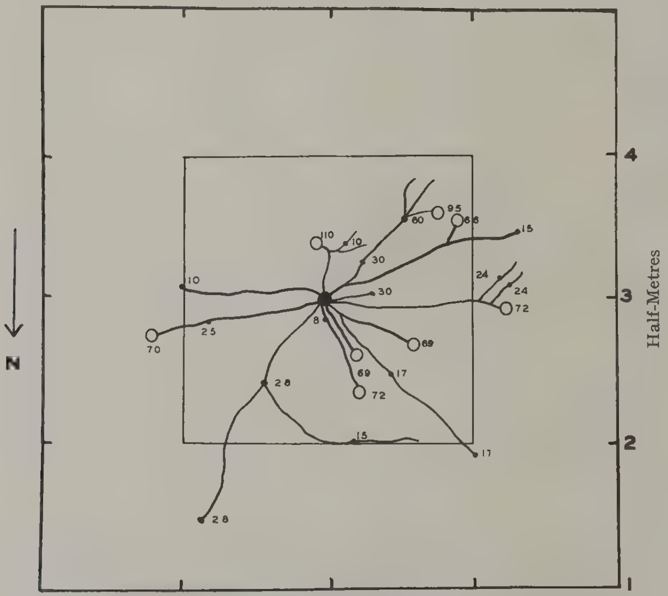


FIG. 11. Root plan of the two-year-old root-system of a layer of No. I, from which the reconstruction shown in Fig. 9 was made.

PLAN OF PLOT.

This clonal material was planted in three "latin squares" with 4 feet between the rows and 6 feet between the plants, in order that the root-systems might develop unhampered by root competition. The stocks were left unpruned at planting to encourage root development as recommended by Knight (39). Originally it was intended to excavate one set of nine trees at the end of the first year and the second at the end of two years. However, by the end of 1934 only four of the trees of Northern Spy had survived transplanting and it was decided to let them grow for another year before excavating. None of the other trees died although it was a very dry summer. This difference in the behaviour of these stocks is an indication of the poor rooting and growth performance of Northern Spy under adverse conditions.

The soil was of the Malling loam series. The subsoil was rather more sandy than usual and the " hassock " was found at the depth of a metre.

Comparison of Root-systems.

Excavations began in March 1936. Three trees each of East Malling Nos. I and IV were excavated and two trees of Northern Spy. Although four trees of the latter were still alive the other two had made such poor growth that they were not worth excavating. Rogers' (38) skeleton method was used in these excavations and a set of three trees was reconstructed for photographing. The best tree of Northern Spy appears in the photograph (Fig. 9) and is also shown in the root map (Fig. 10). Fig. 9 shows that the root-systems of the different stocks were as distinctive as their shoot growth. No. IV had a stout main stem which had produced many short " feathers ", Northern Spy, a thinner main stem which had " feathered " very little, and No. I had produced a more " straggly " shoot system.

The roots of No. IV were branched, fibrous and spread over a 2 metre square occupying the area fairly adequately. This is illustrated in the root map (Fig. 12). Most of the roots did not extend to any great depth, but were within 20 or 30 cm. from the surface (Fig. 9).

The root-system of No. I was not as branched or as extensive as that of No. IV. It only spread over 1 metre square (Fig. 11). The fibre was concentrated round the collar of the tree. There were many more deep roots than on No. IV, some extending to the depth of a metre (Fig. 9).

A study of the root maps shown in Figs. 11 and 12 reveals that No. I had six roots ranging in depth from 60 to 110 cm. within ½ metre of the stem, whereas No. IV had only three deep roots within this distance from the stem, and the deepest of them ended only 80 cm. from the surface. Some of the roots of No. IV which spread farther afield ended at fairly deep levels, 50 to 73 cm. The differences in the spread of the two root-systems is just as striking. All three trees of each variety of rootstock excavated had these same very definite characteristics which are shown by the root maps (Figs. 10, 11, 12). From this evidence it seems obvious that when the root-systems of these two stocks are allowed to develop unrestricted and under comparable conditions, they do have very definite characteristics of their own.

It will be recalled that the trees of Northern Spy did not recover from transplanting from the layer beds nearly so well as did the other rootstocks. The root-systems which they produced in two years therefore did not show a development at all comparable with that of either the trees of No. I or No. IV.

The root-system of Northern Spy was very poor and weak in development. It did not spread, very few roots developed, there was comparatively little fibrous growth round the collar. The system was markedly one-sided and there were no deep roots (Figs. 9 and 10). The root-system shown in Figs. 9 and 10 is the best developed out of the nine Northern Spy trees planted.

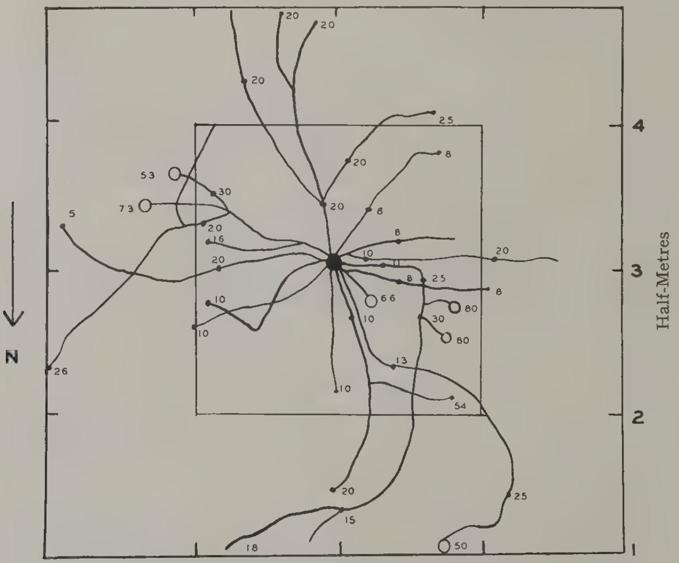


Fig. 12. Root plan of the two-year-old root-system of No. IV. This tree is shown in the photograph in Fig. 9 and the reconstruction was made from this map.

The habit of rooting of these young Spy trees was very similar to that of the older trees direct from Christchurch, New Zealand, already described. It therefore seems safe to conclude that the characteristics observed are common under certain conditions, even though those conditions may be favourable for the development of other root-systems.

OBSERVATIONS ON THE ROOTS OF "STRINGFELLOWED" TREES— BY "SKELETON" AND "BLOCK" METHODS.

A set of "Stringfellowed" trees were also included for excavation. To "Stringfellow" a tree all the roots are cut off as close to the trunk as possible at the time of transplanting. By this means root-systems of the same age are obtained for comparison since all the roots are newly developed. The root-systems produced in two years after this treatment by three- and four-year-old trees of East Malling No. II and Northern Spy were compared.

MATERIAL.

Eight trees of Northern Spy, which had come from New Zealand in 1931, and were about four years old, had to be utilized for this purpose. Four of these trees were, as already described, excavated by the "skeleton" method in 1934, and consequently had become rather dry before they were transplanted for this further test. The eight trees of No. II, which were used as a rough comparison, were only three years old, but they were larger than the trees of Northern Spy, as is shown by their greater average weight of stem at the time of transplanting, viz. No. II 326 gm., Northern Spy 188·2 gm. All the trees were planted in March 1934 in two rows at 6 feet square. The trees of Northern Spy and No. II were planted alternately in the rows. They were not pruned in the year of planting but were lightly pruned in the following year.

EXCAVATION BY SKELETON AND BLOCK METHOD.

Six trees of each variety were excavated in March 1936. Four trees of each variety were excavated by the "skeleton" method (38) two of which were reconstructed and are shown in Figs. 13 and 14.

Of the six trees of Northern Spy, as already noted, three had been examined in detail when excavated in 1934. Hence as a precaution two of these were included in the "skeleton" type of excavation and one in the "block" type in 1936. The figures show that this precaution was justified—the tree on the left in the illustration had been excavated in detail in 1934 whilst the one on the right had been transplanted direct. These were the two best Spy trees excavated in this manner.

The other two of each stock were excavated by a modification of the "block" method in order to obtain a quantitative and qualitative comparison by weight. The excavation for each tree was 2 metres square by 1 metre deep. It was found to be impracticable to weigh each grade of root from each cube of earth separately. The amount to be weighed was too small to allow fresh weights to be taken with sufficient accuracy. If dry weights had been attempted the time taken in weighing such small quantities would have been out of all proportion to the value of the record. In these circumstances it was decided to weigh all the roots from one depth and one grade together. This gives the quantitative and qualitative vertical distribution but not the horizontal distribution.

The soil was very similar to that described in the foregoing excavations (see page 261) but the hassock was sometimes only 90 cm. from the surface and roots of the trees of No. II were found to penetrate to this depth.

QUANTITATIVE RESULTS OF BLOCK METHOD.

It is proposed to deal first with the quantitative results obtained by the block method. These results are tabulated below. The fresh weights of the roots of the two trees of each stock were totalled in drawing up this table.

TABLE II.

Percentage of each Grade of Root and Total weight in grammes at each Depth.

	% Fine.		% Medium.		% Coarse.		% Total Weight.		Total weight, gm.	
Depth.	N. Spy.	II.	N. Spy.	II.	N. Spy.	II.	N. Spy.	II.	N. Spy.	II.
1. 0–17 cm.	20·6	11·3	40·1	25·6	39·3	63·1	51·6	67·7	119·3	516·9
2. 17–34 cm.	21·0	17·0	44·6	41·0	34·4	42·0	40·3	24·3	93·1	185·8
3. 34–50 cm.	36·0	36·0	64·0	63·7	—	—	4·3	4·4	10·0	33·6
4. 50–100 cm.	53·4	46·0	46·6	53·6	—	—	3·8	3·6	8·8	27·6
Percentage in each grade.	22·7	15·0	43·2	32·0	34·1	53·0			Total 231·2	763·9

From this table it is obvious that the total weight of root produced in the two years by the two Northern Spy trees was very much less than that produced by the two trees of No. II. This difference is not entirely due to the original difference in the size of the trees. On the average fresh weight of the stems at planting the trees of No. II were less than twice as large as the trees of Northern Spy, but they have produced more than three times the weight of root in two years. The original stem : root ratio of these trees is not available since during the excavation of the Northern Spy trees the roots became too dry for their weights to be of any value. However, it is interesting to note that the ratio of new stem to new root produced in the two years since planting is about the same for both rootstocks. The figures are given in Table III.

The high percentage of fine roots produced by the Northern Spy trees shown in Table II is due to their lack of coarse root and is not a measure of their fibrous nature. This is confirmed by a comparison of Figs. 13 and 14. The vertical distribution of the roots is expressed in Table II as percentage of the total weight at each depth. The roots of the trees of Northern Spy are spread fairly evenly

TABLE III.

Ratio between the weight of new stem and the weight of new root produced in two years by trees of Northern Spy and No. II.

	Northern Spy.	No. II.
Tree 1	0·58	0·425
Tree 2	0·55	0·574

through the first 34 cm. A greater proportion by weight of the roots of No. II are in the top 17 cm., but this is the result of the concentration of coarse roots round the collar. Both trees have nearly 4 per cent. of their total root weight below 50 cm. In No. II, as can be seen from Fig. 13 and from the table, this figure means quite a large amount of root and in Northern Spy only about one-third of this amount.

DEDUCTIONS FROM RECONSTRUCTED TREES—" SKELETON " METHOD.

A study of Fig. 13 shows the root-system of No. II to be one which occupies the soil fairly fully. It has both shallow and deep roots. Furthermore the roots produced were shallow or deep in character from their inception. The consequence is that the deep roots are mostly situated below the main trunk of the tree. Fig. 14 shows that the root-system produced by Northern Spy does not occupy the soil so efficiently. It is more " straggly ". Roots start as horizontal and then become vertical after they have grown out some distance from the trunk. There is no concentration of deep roots below the trunk and they seem more prone to be produced at the periphery of the system. Once again, the observations upon root development of these plants of Northern Spy seems to confirm those of the other excavations.

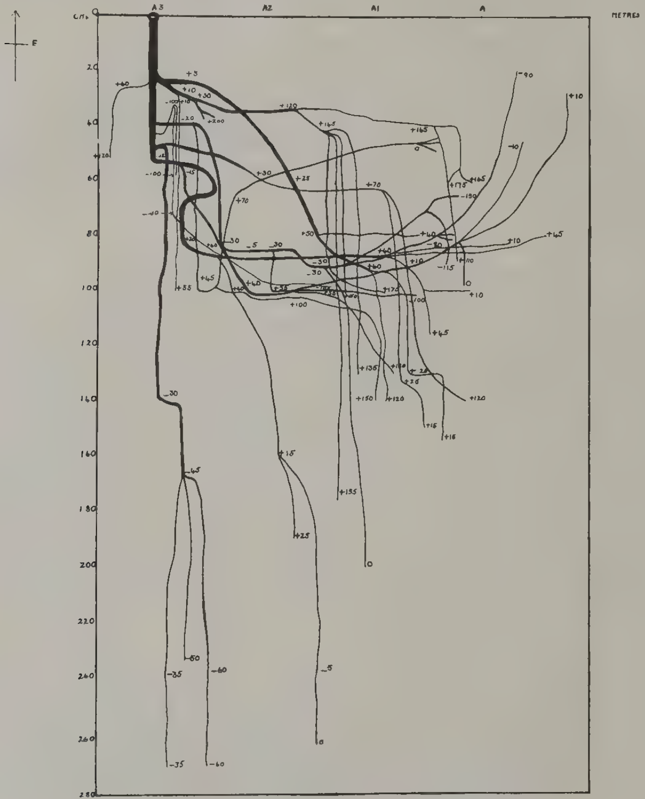
PARTIAL EXCAVATION OF A MATURE TREE ON OWN ROOTS.

An opportunity to study the root-system of a seventeen-year-old tree of Northern Spy on its own roots occurred. It was not possible to excavate the whole tree as it was the only tree of Northern Spy in the arboretum and the " type " tree for the Research Station.

This tree is not very vigorous (height 5·1 metres and spread 4 metres). It bears a few apples in some years but has never been known to bear a heavy crop. There is a poplar hedge about four yards to the north of the tree, and many poplar roots were found during the excavation.

A detailed excavation was made by the " skeleton " method of the east side of the tree in order to obtain a map of the distribution of the roots. The root-system of this side of the tree was reconstructed *in situ* by the use of the map, and the photograph shown in Fig. 15 was obtained.

From the horizontal projection of the spread of the root-system with the vertical distribution indicated by "contour figures", it was possible to make a vertical projection of the root-system in which the horizontal distribution or spread is indicated by figures. This is shown in Fig. 16. In order to make this vertical projection, a datum line was drawn running east and west through the trunk of the tree. Roots lying north of this line are marked minus so many centimetres, and those lying south plus. The number indicates the distance in centimetres from the datum line. This diagram shows roots at between 20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+45
+10
-30
-30
+60
+10
-115
+110
0
+45
+55
+40
+40
+35
+170
+100
+10
+100
+45
+135
+120
+26
+150
+120
+120
+15
+16
-30
+15
-45
+135
+25
0
-50
-35
-60
-5
0
-35
-60

FIG. 16. Vertical projection of portion of the root-system of Northern Spy on its own roots.

and 40 cm. from the surface sending down branches to a depth of 100 to 150 cm. They also turn downwards at the ends. There is another layer of roots running out horizontally for a metre to a metre and a half, at between 80 and 100 cm. from the surface. These also send off vertical branches which penetrate to the rock at a depth of 200 to 260 cm. Many branches from this second stratum of horizontal roots turn upwards at their ends, some growing upwards to within 20 cm. of the surface. The deep roots were conspicuously lacking in fibre but were thickly covered with very large lenticels through which aerenchymatous tissue protruded. These masses of aerenchymatous tissue were pale yellow in colour and might be 2-3 mm. across. When pieces of soil were detached from these roots this aerenchymatous tissue came away with the soil showing that they were in very intimate contact with it. No such structure had been noted in previous excavations at East Malling where deep roots were found. It seems possible that the conditions of limited aeration may be responsible for this unusual growth of aerenchymatous tissue.

On the other side of the tree the soil was removed only to a depth of 20-30 cm., and a scaffolding of roots was found. These had many branches which appeared to descend vertically in a similar fashion to the roots on the east side of the tree. These scaffold roots are shown in Fig. 17.

The soil is red Malling loam. Below 1 metre it becomes very stony and gravelly and the " hassock " was found at a depth of 2-2½ metres. In places at a depth of 2-2½ metres from the surface, just above the " hassock ", pockets of deep red soil of a rather clay-like texture were found. These pockets were the accumulation pockets of the B horizon (38).

The deep roots followed these pockets of rich soil and, when they penetrated to the " hassock ", turned and ran along its surface. Similar conditions were noted by Rogers (38).

The excavation of this tree showed that the root-system of Northern Spy is not always shallow. In this case the roots were nearly as deep as those of any root-system yet excavated on the Research Station. They penetrated to a depth of 260 cm. and the record depth is 296 cm. This tree also demonstrated that deep rooting is not necessarily correlated with vigour.

EXCAVATION OF FIFTEEN-YEAR-OLD TREE GRAFTED ON NORTHERN SPY.

Finally a fifteen-year-old root-system of Northern Spy, worked with Grenadier as a scion variety, was excavated in order to make a complete study of an older root-system. This tree was one of the series in the rootstock trial already referred to and the root-system was from the East Malling clone.

TECHNIQUE FOR DISTINGUISHING ROOTS.

In order to be able to distinguish the roots of the tree to be excavated from those of neighbouring trees, and from the roots of the two stocks of No. XVI which had been "inarched" into its stem for purposes of another experiment, they were injected with dye in the following manner. In October 1935 the top of the tree was cut off and a rubber collar about one foot long was slipped over the butt of the main trunk. Similar smaller collars were fitted to the butts of the three "inarches". These collars were then filled with dye, and supply reservoirs with "automatic feeds" were fitted. Patent blue dye was used for the main trunk. The "inarches" were in a group of three. Tartrazine (yellow) was used for the two "inarches" on the outside of the group and Acid Fuchsin (red) for the "inarch" in the centre. The dyes used were 0·2 per cent. solutions and alcohol was added to prevent freezing. The roots were allowed to remain connected with the reservoirs of dye till March 1936, when the excavation commenced. Complete penetration of all the roots was probably obtained months before this. The penetration of dyes in apple trees has been described by Roach (40).

POSITION OF THE TREE.

This tree was surrounded by four others of Lane's Prince Albert on rootstocks of very different habit and vigour. The tree on the north was on the very dwarfing East Malling No. VIII rootstock, that on the south on vigorous East Malling No. XV, that on the west on very vigorous East Malling No. XVI, and that on the east on vigorous East Malling No. II. The trees were planted at 4½ metres square. The excavation was carried out by the "skeleton" method (38). In order to include most of the roots, an excavation 5 metres wide (from east to west) and 6 metres (from north to south) and a metre and a half deep, had to be made. A map of the Northern Spy root-system and of the root-systems of the No. XVI "inarches" was made, but for the sake of clarity these latter have been excluded from Fig. 18. The root-systems were reconstructed and the top of the tree replaced for the photographs shown in Figs. 19 and 20.

THE SOIL.

There was a surface layer of dark friable soil about 20 cm. thick, below which the red Malling loam extended for about 40 cm. Below this again there was more clay in the loam and scattered stones. At about 80-90 cm. from the surface there was a layer of clayey material thickly interspersed with stones which might be 6-9 inches in diameter. This layer is locally known as "pinnock", and in it were found a few dark coloured accumulation pockets. Under this, the "hassock", (uncemented Kentish ragstone, which is the underlying rock in this series) was found only at a depth of more than a metre.

THE EXCAVATION AND EFFECT OF COMPETITION.

The Northern Spy root-system was very one-sided. This is clearly shown by the root map (Fig. 18) and is further illustrated in Figs. 19 and 20. Practically no roots were found in the south-east quadrant. This space was occupied by roots from the Lane's Prince Albert tree on No. II which was on the east, and by the roots of the tree on No. XV which was on the south side of the Grenadier.

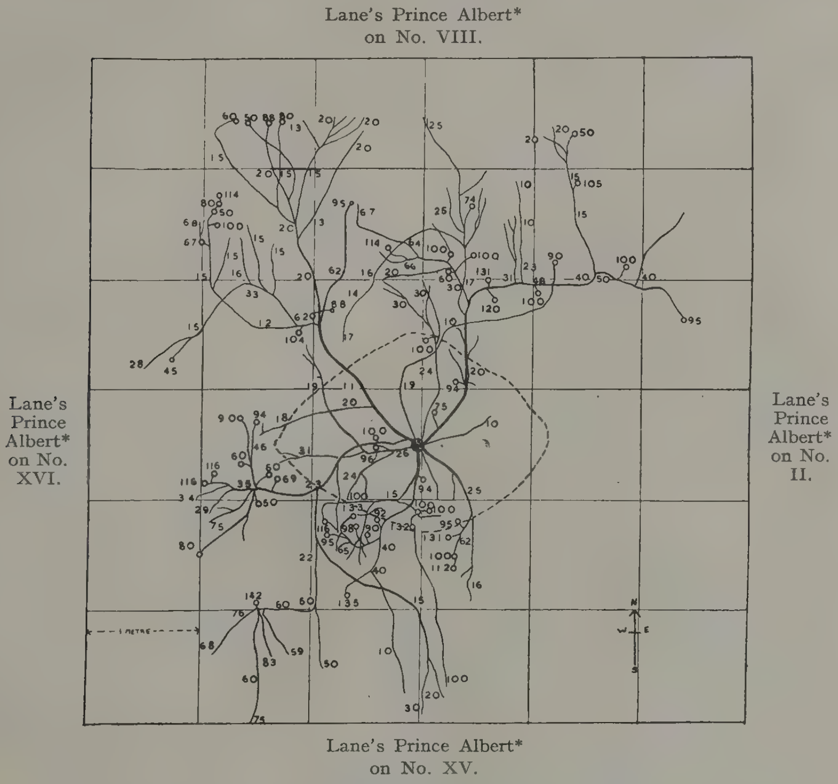
Lane's Prince Albert* on No. VIII.
Lane's Prince Albert* on No. XVI.
Lane's Prince Albert* on No. II.
Lane's Prince Albert* on No. XV.
1 METRE
N
W
E
S

FIG. 18. Root map of a fifteen-year-old Grenadier on Northern Spy from which the reconstruction shown in Figs. 19 and 20 was made. The dotted line represents the spread of the branches. This tree was surrounded by four trees on Lane's Prince Albert on various rootstocks as indicated.

Roots from the tree on No. II were found at a depth of a metre immediately below the trunk of the tree on Northern Spy. Fig. 19 shows how the main roots of the Northern Spy all left the trunk at the same level and radiated horizontally for some distance. The character of the root-system was very different on the north and south sides. The root map, Fig. 18, shows the difference in the area occupied by the roots. Fig. 20 shows how on the south deep roots are produced near the trunk whilst on the north of it no deep roots occur within one and a half metres. From the map it can be seen that on the south the roots branch within a distance of one metre from the trunk, while on the north the two main roots run out for over a metre before they branch at all. Fig. 20 shows that the roots on the south are much finer than those on the north. On the south some of the roots remained within 20-30 cm. of the surface, but many descended to the "hassock" within the first metre. The smaller branches of the tree were also on the south side, as can be seen from their diameter at the fork, which is illustrated in Fig. 20. Roach (40) has shown that there may be a connection between certain branches and certain roots in a tree, one main root supplying one main branch. Incidentally this was confirmed by the course taken by the dyes injected into the "inarched" rootstocks, the details of which will be described later elsewhere. In spite of the fact that the root-system on the south of this tree had a number of deep roots it was weak and poorly developed, and was connected with the weaker part of the branch system.

---

* These indicate position and nature of adjoining trees.

The root-system on the north side of the tree, as can be seen from the map (Fig. 18), consisted chiefly of two main roots, which run out horizontally (Fig. 20) about 20 cm. from the surface, without branching, for a distance of over a metre. After this they break up into many smaller branches, some of which continued at about 20-30 cm. from the surface of the soil for a further two metres and more. Others penetrated to the "hassock" at a depth of over a metre. At three metres from the trunk some roots from the Lane's Prince Albert on No. VIII were found. At this distance from the trunk several roots of the Northern Spy still continued in a northerly direction for another half metre and were intermingled with the No. VIII roots. At this stage they had to be cut off because further excavation would have destroyed too many of the No. VIII roots. The trench was then within one metre of the trunk of the tree on No. VIII.

On the west, many roots of the Lane's Prince Albert on No. XVI were found during the excavation, especially in the south-west corner, at a distance of only two and a half metres from the excavated area. Fig. 20 shows that the larger branches of the tree are on the north side. They are connected with the larger and more extensive side of the root-system.

Summing up, there was a difference in the development between the north and south sides of both the roots and the top of this tree. This corresponds with a difference in the environment of the roots. Root competition was intense on the south, south-east and south-west and the Northern Spy root-system in this area was poorly developed. There was much less competition on the north, north-east and north-west where the Northern Spy root-system had developed much more vigorously and was shallow until other roots were met. This development suggests that, under these conditions, if there had been no root competition with the Lane's Prince Albert trees, the roots would have continued to radiate at a depth of about 20-30 cm. from the surface and would have produced a more vigorous root-system and tree. When, apparently as a result of root competition, they penetrated to deeper levels they did not develop so vigorously.

ACKNOWLEDGMENTS.

The author wishes to thank the staff as a whole at East Malling for the help and advice given to her throughout her stay, and thanks are especially due to Mr. W. S. Rogers in connection with the root excavation work and to the Imperial Bureau of Fruit Production for editorial assistance.

SUMMARY.

1. A survey of literature is made.

2. The root habit of Northern Spy apple was investigated by detailed excavation of the root-systems of a number of young Northern Spy trees ranging from two to six years old, and a section of a seventeen-year-old tree; and also a complete fifteen-year-old tree of Grenadier on Northern Spy rootstock. Young trees of Ivory's Double Vigour and Malling Stocks Nos. I, II, IX and IV were excavated for comparison. In all, forty-seven trees were excavated. Comparisons were also available with the root-systems of older apple trees of other varieties previously excavated from the same soil type.

3. A description of the excavation technique is given.

4. Variation in the type of root and top growth among a collection of plants sent from New Zealand is noted. Two distinct types are illustrated.

5. Four-year-old trees of Northern Spy excavated from nursery rows showed considerably less vigour both of root and branch than comparable trees of Ivory's Double Vigour. The roots of the latter had a more marked downward tendency than those of the former, though the deepest root found in this series was a Northern Spy root.

6. In a plot of nine clonal layers each of Northern Spy and Stocks I and IV, only four Northern Spys remained alive after one dry summer though all the other stocks grew well. This illustrates the poor power of recovery of Northern Spy after transplanting—a fact noted throughout the investigation. This plot was widely spaced to avoid root competition.

Two years after planting, three trees each of Nos. I and IV, and the two best Northern Spys were excavated. Distinctive root characteristics were found. The root-systems of the Northern Spys were weak, sparse, one-sided, and poorly developed, with little fibre.

The No. I roots occupied just over a square metre of soil. There was much fibre round the collar of the tree and many roots extending to a depth of 60-110 cm. The No. IV trees showed most vigour. Their mean root spread was nearly two metres. On the whole their roots were shallower than those of No. I and about half of the deep roots occurred near the periphery of the root-system.

7. Six Northern Spy trees six years old were excavated and compared with six trees of No. II, five years old. Both sets of trees had been stringfellowed (i.e. all roots were removed) and replanted two years previously. Root weights were obtained in various soil regions for two trees of each set. The trees of No. II were less than twice as heavy as those of Spy at the time of planting, but they produced more than three times as much root as the Spy trees in the two years preceding excavation. This is another measure of the relatively slow recovery power of Spy. The ratio of new root weight to new stem weight was similar in both Spy and No. II.

The percentage of total root weight at more than 34 cm. deep was 8·1 for Northern Spy, and 8·0 for No. II.

The No. II root-systems spread in all directions. Roots penetrated downwards as well as outwards from the trunk. The Spy root-systems remained nearer the surface near the trunk, but some roots turned downwards near the periphery of the root-system.

The whole series of excavations gives the impression that the root-system of Spy, developing unhampered by outside root competition, forms a shape rather like a tin lid. The main scaffolding appears to be shallow, and such deep roots as are formed occur near the extremities.

The root-systems of Stocks Nos. I and II, and Ivory's Double Vigour, however, in the first two years, appear to spread evenly in all directions from the trunk, thus filling a volume of soil like half a ball, cut at the soil surface. No. IV approaches the Spy formation, though not in so marked a degree. These characteristics are modified by soil factors and root competition.

8. A seventeen-year-old Spy tree partly excavated had roots descending to 260 cm. Some of these were directly below the trunk (although no "tap roots" were found in any of these excavations). It is thought that this departure from the habit noted in younger trees is due to severe root competition from an adjacent poplar hedge.

A marked development of aerenchyma tissue, not reported on other rootstocks, was found on the deep Northern Spy roots. This may be an indication that the Northern Spy roots are not well adapted to deep and less well aerated soil regions.

9. The complete excavation of a fifteen-year-old Grenadier on Northern Spy rootstock, growing in a plantation between other trees on various rootstocks

of differing vigour, showed clearly both the weak uneven growth habit of Northern Spy, and the effect of root competition.

On the side next to a small tree on a very dwarfing stock, the Spy root-system spread more than three metres from the trunk, mainly at a depth of less than 30 cm. but sending down vertical roots in the region where roots from the other tree were growing.

On the opposite side, the roots of a tree on a vigorous rootstock approached quite close to the Northern Spy. Here the Spy roots grew much deeper—apparently through the competition of the other roots. The deep roots were not vigorous, however, and were found to be connected with the weaker side of the very one-sided branch system. This latter point was proved by a dye injection technique.

10. In general, it appears that Northern Spy has a very distinctive natural root habit, and is not able to adapt itself to uncongenial surroundings.

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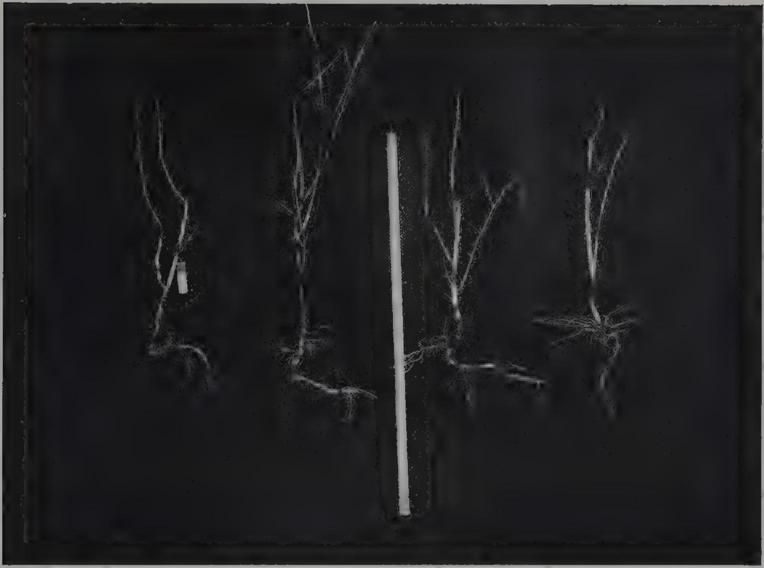


FIG. 1. Northern Spy root cuttings from Auckland. Planted 1931. Lifted 1934. Poor growth and poor root-systems with a shallow rooting habit.

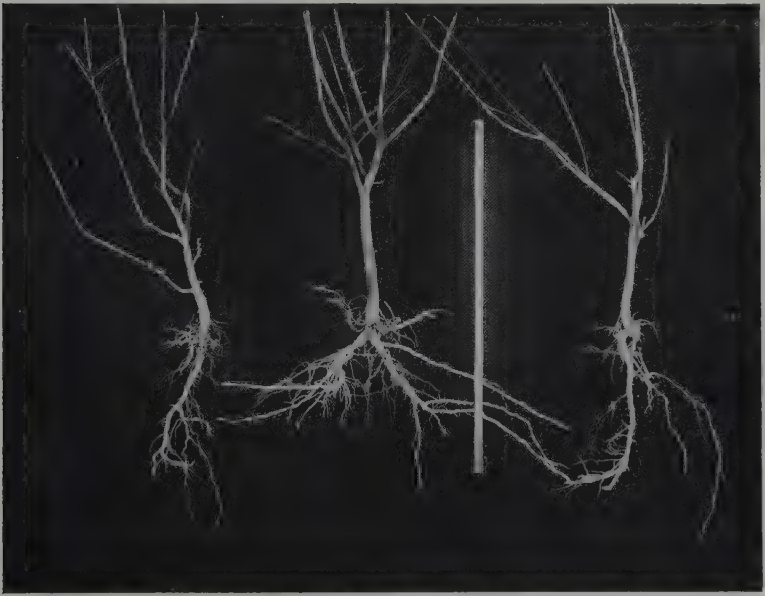


FIG. 2. Northern Spy root cuttings from Auckland. Planted 1931. Lifted 1934. Strong growth and strong root-systems with a deep rooting habit.

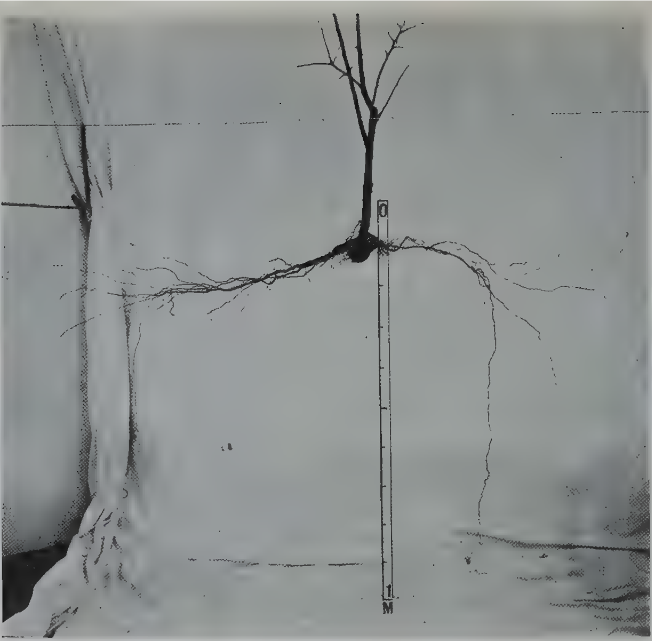


FIG. 3. Root-system of a Northern Spy tree, four years old. Sparse one-sided root-system. Deep roots produced as branches from horizontal roots at the periphery of the system.

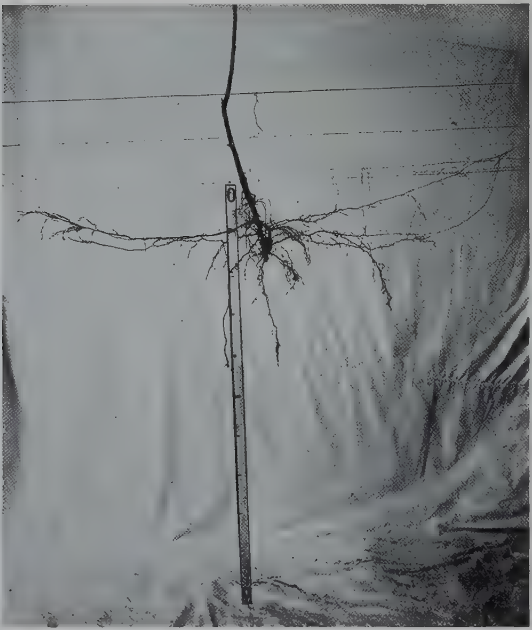


FIG. 4. Root-system of No. IX, three years old. Deep roots below the trunk. Rather fibrous roots.

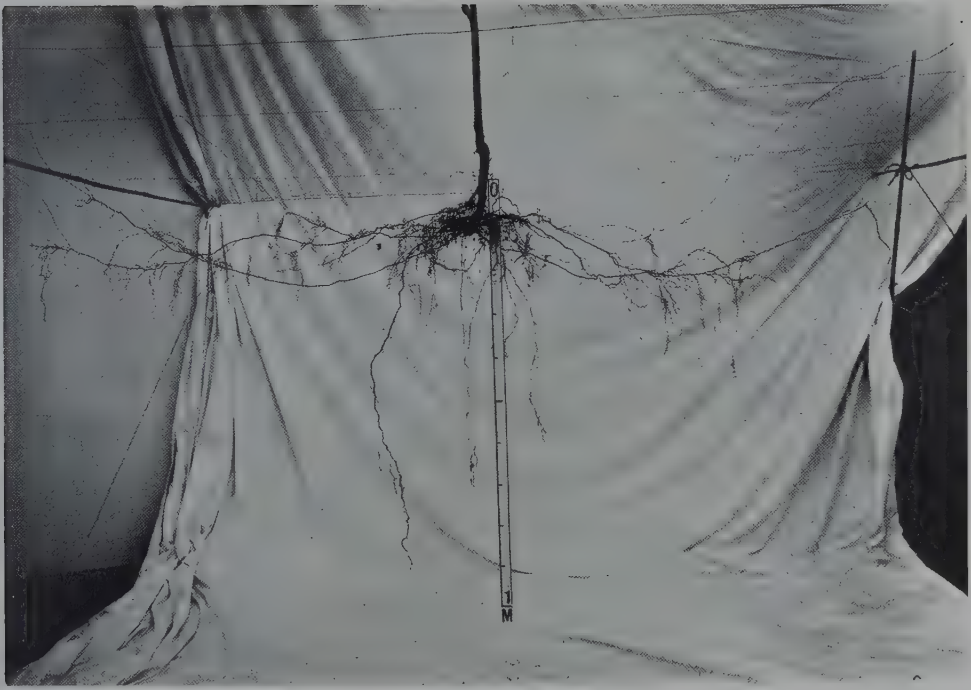


FIG. 5. Root-system of Ivory's Double Vigour, four years old. Deep roots concentrated under the trunk of the tree. Roots of a rather fibrous nature.

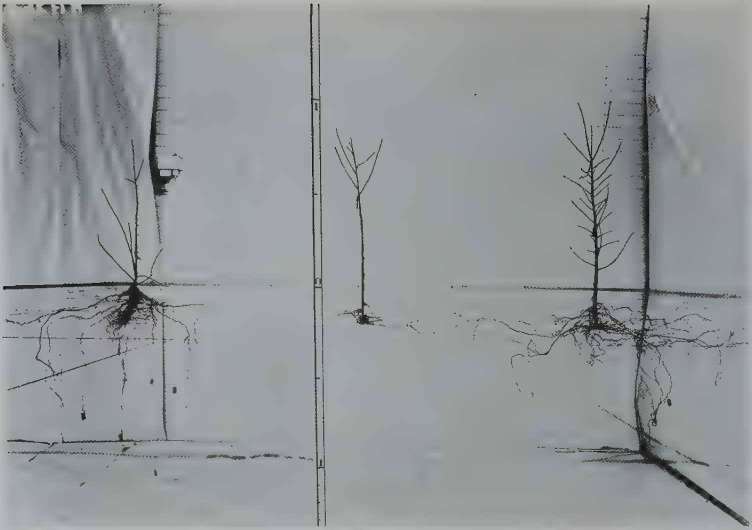


FIG. 9. Root-system produced by layers in two years. Reading from left to right: No. I, Northern Spy and No. IV. No. I more deep than spreading. Northern Spy neither spreading nor deep. No. IV more spreading than deep.

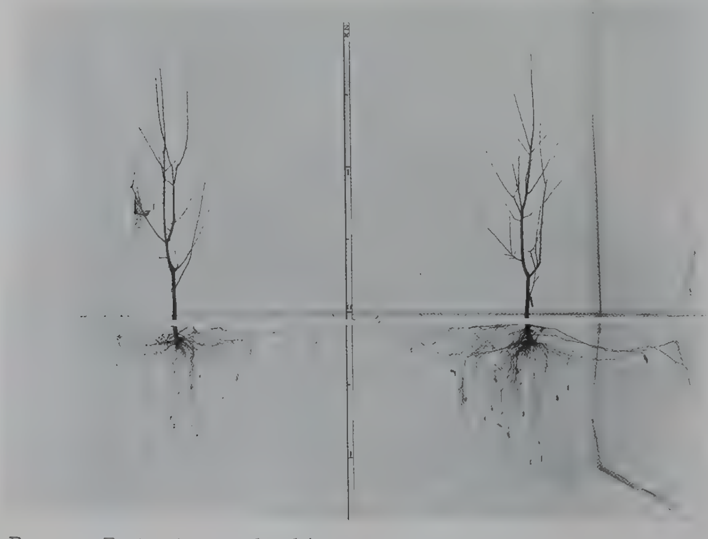


FIG. 13. Root-systems produced in two years by No. II (five years old) when "stringfellowed" at planting.

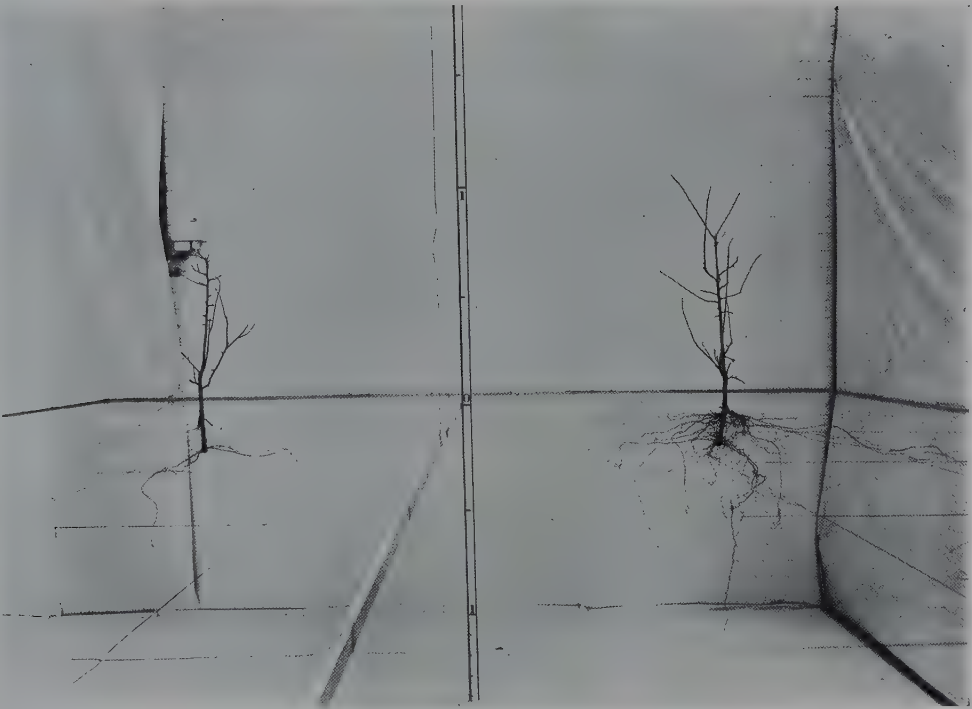


FIG. 14. Root-systems produced in two years by Northern Spy (six years old) when "stringfellowed" at planting. Tree on right, dug up in 1934. Tree on left, excavated 1934.

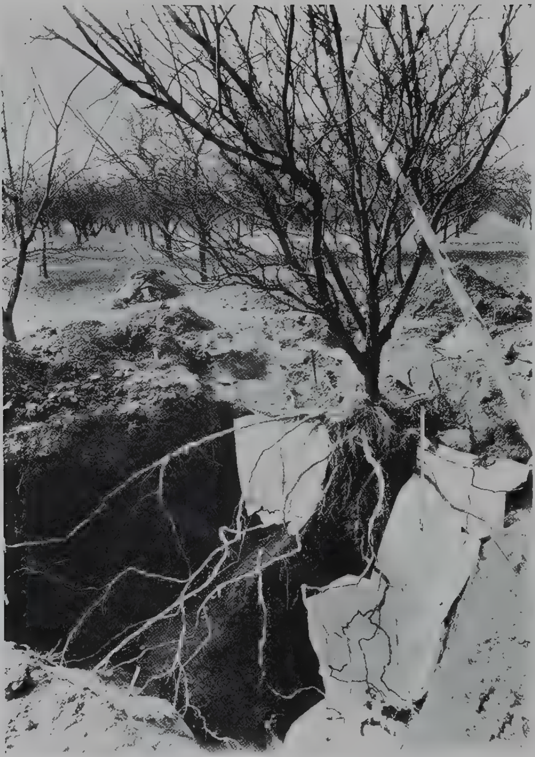


FIG. 15. A seventeen-year-old tree of Northern Spy on its own roots. Surface scaffolding of roots producing deeper roots as branches. From east.

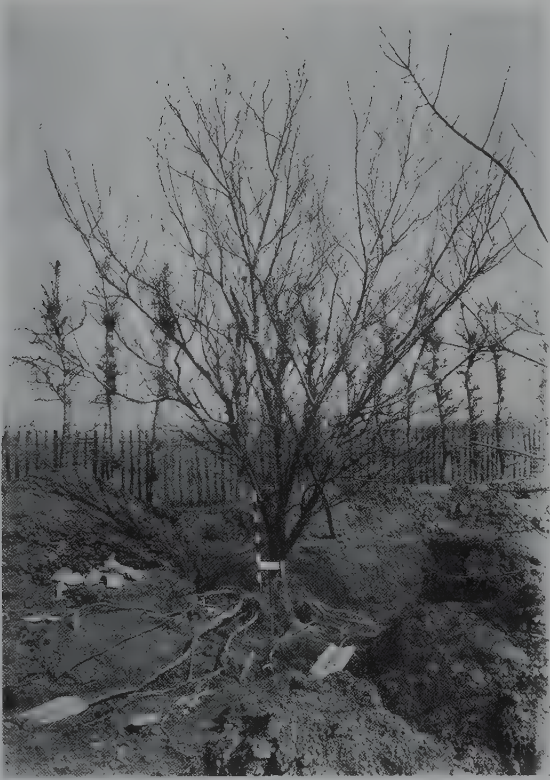
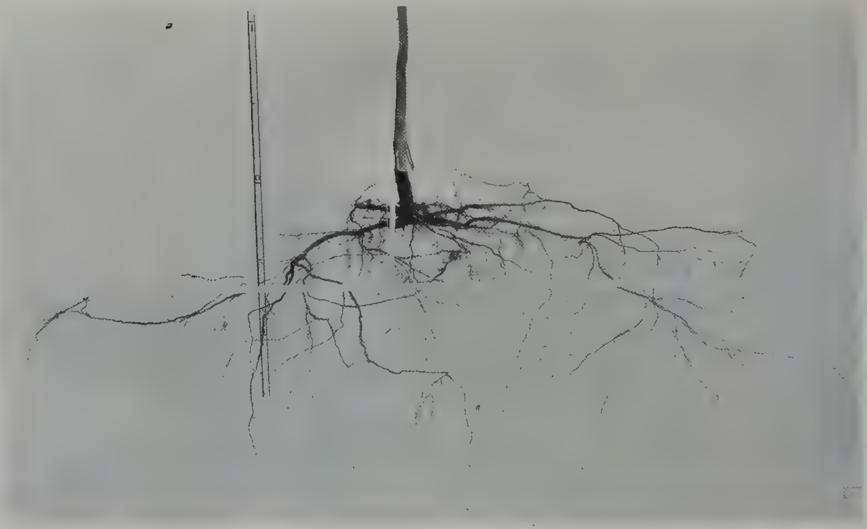


FIG. 17. A seventeen-year-old tree of Northern Spy on its own roots. Surface scaffolding of roots from south west.

Lane's Prince Albert* on No. XV.



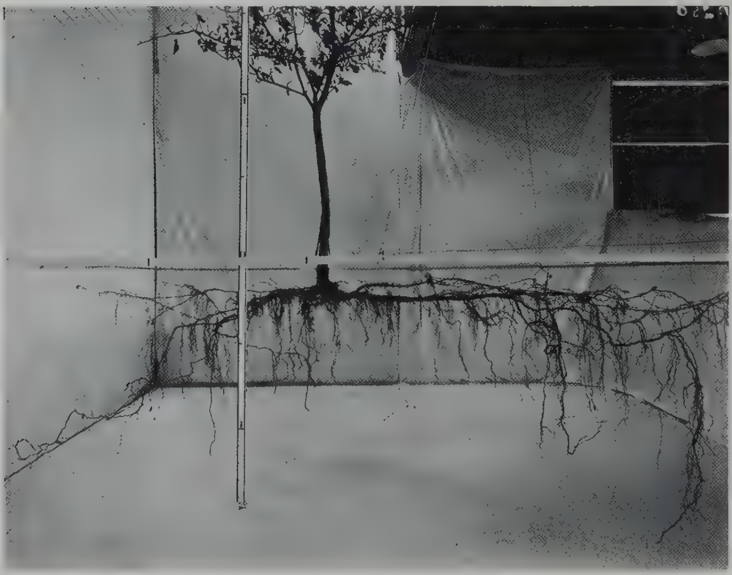
Lane's Prince Albert* on No. II.

Lane's Prince Albert* on No. XVI.

Lane's Prince Albert* on No. VIII.

FIG. 19. Northern Spy root-system fifteen years old. Top worked with Grenadier.

Lane's Prince Albert* on No. XVI.



Lane's Prince Albert* on No. XV.

Lane's Prince Albert* on No. VIII.

Lane's Prince Albert* on No. II.

FIG. 20. A fifteen-year-old Grenadier on Northern Spy. Note deep rooting nearer the trunk on south and shallow root-system extending for over one metre on north before any deep roots occur.

* These indicate nature and position of adjoining trees.

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GAS-STORAGE OF FRUIT IV.

COX'S ORANGE PIPPIN APPLES*

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Gas-storage trials with Cox's Orange Pippin apples were carried out in 1931-2, 1932-3 and 1933-4. In the first two seasons only a single gathering of fruit was used, but in 1933-4 two gatherings were made, the earlier gathered apples being in the pre-climacteric condition when gathered (respiratory activity in air at 59° F. =64 c.cm. per 10 kg. hr.), whilst those gathered later were on the climacteric rise in respiratory activity, its value in air at 59° F. being 98 c.cm. per 10 kg. hr.

The dates of gathering, etc., were as follows :—

Season.	*Date of gathering.*	*Locality.*	*Soil.*
1931-2	21/9/31	Chelmsford	Valley gravel with a boulder clay matrix.
1932-3	26/9/32	Burwell, nr. Cambridge	Chalk.
1933-4			
(1st pick)	5/9/33	Kirdford, Sussex	Wealden clay.
(2nd pick)	26/9/33	,, ,,	,, ,,

The interval between the gathering of the fruit and the closing of the storage chambers was 2 days in 1933-4, 4 days in 1932-3, and 5 days in 1931-2.

Grading and Sampling.

The technique described in a previous paper in this series (3, p. 150) was adopted for the grading, handling and sampling of the fruit. Oiled wrappers containing not less than 15 per cent. by weight of mineral oil were used for all the fruit.

The Storage Conditions.

The gas-storage installation at the Ditton Laboratory, which was fully described in the paper referred to above (l. c., p. 151), was used in all three seasons. In the first season (1931-2) the following storage conditions were tested : three temperatures, namely 1° C. (34° F.), 4° C. (39° F.) and 10° C. (50° F.), and at each of these temperatures ten different atmospheres, namely :—

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* Brief references to the results obtained with this variety of apple in gas-storage have already been made (1 and 2).

5% carbon dioxide with 2·5%, 5% and 10% oxygen.
10% ,, ,, ,, ,, ,, ,, ,,
15% ,, ,, ,, ,, ,, ,, ,,
No carbon dioxide with 21% oxygen (i.e. air mixture).

In each case the remaining percentage was made up with nitrogen.

In the second season (1932-3) the same three temperatures, namely 34° F., 39° F., and 50° F., were used. An atmosphere consisting of 5 per cent. carbon dioxide and 15 per cent. oxygen was substituted for the gas-mixture containing 10 per cent. oxygen and 15 per cent. carbon dioxide. This change was made because it was thought desirable to test an atmosphere which could be obtained and maintained by the simple method of restricted and controlled ventilation, as employed in the commercial gas-storage of the Bramley's Seedling variety.

For the experiments conducted in 1933-4 a narrower range of temperatures was selected, the results of the two previous seasons having made it clear that a temperature of 50° F. was too high for the successful gas-storage of apples. The temperatures chosen were accordingly 34° F. (1° C.), 37·5° F. (3° C.), and 41° F. (5° C.).

For the first time in these gas-storage trials atmospheres containing a lower percentage of oxygen than that present in normal air, but no carbon dioxide, were used for comparison with atmospheres containing similar percentages of oxygen, but with 5, 10 and 15 per cent. of carbon dioxide.

In the storage trials of 1933-4 Worcester Pearmain apples which were gathered when at the peak of their respiratory activity and which had therefore reached the post-climacteric phase, were stored with the Cox's Orange Pippin apples. From what is now known (4) these post-climacteric apples were undoubtedly evolving ethylene in sufficient quantities to stimulate the climacteric in the Cox's Orange Pippins that were stored with them. The effect upon the Cox's Orange Pippins was very marked, not only in accelerating their ripening through the effect of ethylene upon the climacteric, but also in causing severe spotting round the lenticels, which, although definitely functional in origin, was often followed by fungal invasion of the injured tissues. This spotting was sufficiently severe to vitiate completely the storage results, at least as regards actual wastage. They have therefore been omitted from the following sections.*

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* The disastrous effect upon unripe Cox's Orange Pippin apples of storing them with ripe Worcester Pearmains is clearly brought out by the following comparison. Whereas the commercial storage life of these apples when stored with ripe Worcesters was only three weeks in air, and less than eight weeks under the best gas-storage conditions tested, similar fruit stored in the absence of the Worcesters had a commercial storage life of 21 weeks in an atmosphere containing 10 per cent. oxygen plus 10 per cent. carbon dioxide at 40° F. Moreover this atmosphere, as will be seen below (p. 286), is not one of those most suitable for the Cox's Orange Pippin variety.

CRITERIA AS TO CONDITION OF FRUIT.

The following observations were made at each examination :—

(1) Ground colour, using Ridgway's colour standard.*

(2) Firmness of flesh (measured by a penetrometer).†

(3) Browning of flesh tissues : (*a*) brown-heart type, (*b*) breakdown type, and (*c*) core-flush type. These are estimated as *prevalence* and as *intensity*. Intensity is measured as the percentage of the flesh showing browning in a median transverse section of the fruit. Data for wastage from browning of the flesh are also presented as *total amounts* (=prevalence × intensity, expressed as percentage).

(4) Fungal rotting, expressed as prevalence only. An apple was assessed as rotting when an active rot exceeding 2 mm. in diameter was observed.

(5) Flavour, aroma and cooking quality. After storage for long periods apples may appear quite sound, as judged by any of the above criteria, but may have lost their characteristic flavour and consistency. Apples in such a condition are described as being over-ripe, a stage which, within the limits of the personal equation, can be precisely defined and definitely marks the limit of storage life.

(6) Wilting. Under the conditions of these experiments no obvious wilting occurred even after the longest period of storage tested.

STORAGE RESULTS.

The storage results cannot be summarized in any simple tabular form because one must take into account not only the effect of the storage conditions upon the development of wastage, whether it be due to low-temperature breakdown, core-flush or fungal rotting, but also the condition of the fruit as regards its flavour, consistency, colour, etc.

TYPES OF WASTAGE.

In the first place the various definite types of wastage met with in the course of the experiment will be considered in detail. Tables I to VI show quantitatively the results as regards the development of the various types of wastage. These results are presented in the same form as in the previous paper of this series (3). In studying these Tables it should be borne in mind that the figures for wastage shown at any examination are based on a single sample of fruit.

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* R. Ridgway : "Colour Standards and Colour Nomenclature." Washington, D.C., 1912.

† The type of instrument used in these tests is illustrated and described in Department Circular No. 350 of the U.S. Department of Agriculture, Washington, September, 1925. The diameter of the plunger fitted to this instrument was 7 mm. and the depth of penetration 7 mm. The skin of the apples to be tested was first removed by slicing off an area about three-quarters of an inch in diameter.

Table I.

Cox's Orange Pippin Apples (1931-2).

O_2 %	CO_2 %	Brownheart at 34° F.												Low-temperature breakdown at 34° F.					
		4/11/31 (37 days)			3/12/31 (66 days)			13/1/32 (107 days)			1/3/32 (155 days)			13/1/32 (107 days)			1/3/32 (155 days)		
		Prevalence.	Total Amount.	Intensity.	Prevalence.	Total Amount.	Intensity.	Prevalence.	Total Amount.	Intensity.	Prevalence.	Total Amount.	Intensity.	Prevalence.	Total Amount.	Intensity.	Prevalence.	Total Amount.	Intensity.
2·5	5	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	24	**5**	20	100	**20**	20
5·0	5	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	45	**9**	20	100	**40**	40
10·0	5	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	65	**13**	20	100	**20**	20
2·5	10	10	**2**	20	7	**42**	60	21	**9**	43	21	**4**	20	79	**16**	20	100	**60**	60
5·0	10*	96	**48**	50	100	**67**	67	100	**82**	82	—	—	—	—	—†	—	—	—†	—
10·0	10	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	86	**34**	40	100	**60**	60
2·5	15	93	**53**	57	93	**61**	66	100	**89**	89	—	—	—	—	—†	—	—	—†	—
5·0	15	72	**20**	28	72	**20**	28	52	**17**	34	—	—	—	100	**40**	40	100	**80**	80
10·0	15	70	**17**	25	55	**19**	35	52	**22**	43	—	—	—	100	**60**	160	100	**80**	80
21·0	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	14	**3**	20	100	**60**	60

* The concentration of CO_2 exceeded 15% for 2 to 3 days during the first period.

Note 1. Fungal wastage was negligible at this temperature of storage.

Note 2. In Tables I to VI the figures for each examination are based on a single sample. There are bound to be inherent differences between samples, however carefully they are prepared. It is, therefore, necessary to consider the results as a whole rather than individually.

Note 3. The earlier observations, when wastage was nil or only negligible in amount, have been omitted.

† Observations upon breakdown impossible owing to the masking effect of brownheart.

TABLE II.

Cox's Orange Pippin Apples (1931-2).

O_2 %	CO_2 %	Brownheart at 39° F.												Core-flush at 39° F.					
		4/11/31 (37 days)			3/12/31 (66 days)			13/1/32 (107 days)			1/3/32 (155 days)			13/1/32 (107 days)			1/3/32 (155 days)		
		Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.
2·5	5	0	0	**0**	0	0	**0**	0	0	**0**	3	20	**0·5**	0	0	**0**	17	33	**5**
5·0	5	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	28	33	**9**	72	36	**26**
10·0	5	0	0	**0**	0	0	**0**	0	0	**0**	3	20	**0·5**	21	33	**7**	76	46	**35**
2·5	10	3	20	**0·5**	21	20	**4**	11	20	**2**	20	30	**6**	0	0	**0**	21	33	**7**
5·0	10	0	0	**0**	0	0	**0**	0	0	**0**	11	25	**27**	7	33	**2**	72	40	**29**
10·0	10	0	0	**0**	0	0	**0**	0	0	**0**	6	40	**2·5**	10	33	**3**	82	60	**49**
2·5	15	48	21	**10**	51	36	**18**	35	36	**13**	34	56	**20**	0	0	**0**	13	45	**6**
5·0	15	6	40	**2·5**	11	20	**2**	6	20	**1**	11	20	**2**	3	33	**1**	65	45	**29**
10·0	15	0	0	**0**	3	20	**0·5**	11	25	**3**	38	25	**10**	0	0	**0**	76	40	**30**
21·0	0	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	45	45	**20**

TABLE III.

Cox's Orange Pippin Apples (1931-2).

O$_2$ %	CO$_2$ %	Brownheart at 50° F.												Core-flush at 50° F.						Fungal wastage at 50° F.		
		4/11/31 (37 days)			3/12/31 (66 days)			13/1/32 (107 days)			1/3/32 (155 days)			13/1/32 (107 days)			1/3/32 (155 days)			3/12/31 (66 days)	13/1/32 (107 days)	1/3/32 (155 days)
		Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.	Prevalence.	Prevalence.	Prevalence.
2·5	5	10	20	**2**	7	20	**2**	0	0	**0**	20	20	**4**	21	33	**7**	31	33	**10**	0	7	0
5·0	5	31	45	**14**	83	22	**20**	59	26	**15**	62	20	**13**	0	0	**0**	62	54	**33**	0	0	17
10·0	5	0	0	**0**	13	20	**3**	0	0	**0**	0	0	**0**	42	33	**14**	55	64	**35**	0	3	21
2·5	10*	90	37	**33**	93	40	**37**	93	40	**37**	—†	—	—	0	0	**0**	0	0	**0**	0	31	51
5·0	10	90	31	**28**	100	35	**35**	100	39	**39**	—†	—	—	21	33	**7**	31	41	**13**	0	3	51
10·0	10	30	30	**9**	30	25	**7**	24	46	**11**	10	33	**3**	42	33	**14**	83	74	**61**	3	3	10
2·5	15	90	20	**18**	83	31	**26**	100	36	**36**	—†	—	—	0	0	**0**	0	0	**0**	7	35	70
5·0	15	83	26	**22**	86	42	**36**	100	46	**46**	—†	—	—	14	33	**5**	31	33	**10**	0	0	31
10·0	15	80	32	**26**	100	45	**45**	96	47	**45**	—†	—	—	7	33	**3**	17	40	**7**	0	10	83
21·0	0	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	14	33	**5**	10	59	**6**	0	14	56

* The concentration of CO$_2$ reached 15% soon after the beginning of the experiment.

† Figures not given owing to the marking effect of fungal wastage at this stage.

TABLE IV.

Cox's Orange Pippin Apples (1932-3).

O₂ %	CO₂ %	Low-temperature breakdown at 34° F.									Core-flush at 34° F.									Fungal wastage at 34° F.		
		26/1/33 (118 days)			2/3/33 (153 days)			28/3/33 (179 days)			26/1/33 (118 days)			2/3/33 (153 days)			28/3/33 (179 days)			26/1/33 (118 days)	2/3/33 (153 days)	28/3/33 (179 days)
		Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.	Prevalence.	Prevalence.	Prevalence.
2·5	5	0	0	**0**	0	0	**0**	4	20	**1**	0	0	**0**	0	0	**0**	0	0	**0**	4	8	12
5·0	5	0	0	**0**	4	20	**1**	8	20	**2**	4	33	**1**	0	0	**0**	44	66	**29**	8	12	20
10·0	5	0	0	**0**	0	0	**0**	0	0	**0**	16	33	**5**	16	33	**5**	32	33	**10**	8	8	4
15·0	5	0	0	**0**	0	0	**0**	0	0	**0**	24	20	**5**	44	36	**16**	68	58	**40**	4	8	12
2·5	10	0	0	**0**	44	24	**10**	64	40	**25**	12	33	**4**	0	0	**0**	16	66	**11**	0	20	8
5·0	10	4	20	**1**	0	0	**0**	28	56	**16**	4	33	**2**	12	33	**4**	44	71	**31**	4	16	16
10·0	10	0	0	**0**	72	24	**17**	12	20	**2**	8	33	**3**	20	36	**7**	64	66	**42**	0	8	16
2·5	15	0	0	**0**	92	30	**27**	100	52	**52**	28	36	**10**	52	44	**23**	64	66	**42**	4	32	24
5·0	15	20	20	**4**	96	32	**31**	100	60	**60**	64	56	**36**	72	56	**40**	100	100	**100**	20	16	24
21·0	0	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	12	32

TABLE V.

Cox's Orange Pippin Apples (1932-3).

O_2 %	CO_2 %	Core-flush at 39° F.												Fungal wastage at 39° F.			
		14/12/32 (75 days)			26/1/33 (118 days)			2/3/33 (153 days)			28/3/33 (179 days)			16/11/32 (47 days)	14/12/32 (75 days)	26/1/33 (118 days)	2/3/33 (153 days)
		Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.	Prevalence.	Prevalence.	Prevalence.	Prevalence.
2·5	5	0	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0	4	8
5·0	5	0	0	**0**	8	66	**5**	4	33	**1**	48	66	**32**	0	4	8	12
10·0	5	0	0	**0**	40	33	**13**	16	36	**6**	84	40	**33**	0	0	0	8
15·0	5	0	0	**0**	24	35	**8**	24	40	**10**	4	66	**3**	0	0	8	8
2·5	10	0	0	**0**	0	0	**0**	8	33	**3**	8	33	**3**	0	0	0	16
5·0	10	0	0	**0**	24	33	**8**	12	40	**5**	52	36	**19**	0	4	16	28
10·0	10	0	0	**0**	28	37	**10**	40	37	**15**	76	50	**38**	0	4	4	12
2·5	15	0	0	**0**	0	0	**0**	12	33	**4**	4	33	**1**	0	8	8	20
5·0	15	0	0	**0**	12	33	**4**	28	50	**14**	15	40	**6**	0	0	4	16
21·0	0	0	0	**0**	0	0	**0**	0	0	**0**	40	40	**16**	0	4	4	12

TABLE VI.

Cox's Orange Pippin Apples (1932-3).

O₂ %	CO₂ %	Brownheart at 50° F.						Core-flush at 50° F.									Fungal wastage at 50° F.				
		26/1/33 (118 days)			2/3/33 (153 days)			14/12/32 (75 days)			26/1/33 (118 days)			2/3/33 (153 days)			16/11/32 (47 days)	14/12/32 (75 days	26/1/33 (118 days)	2/3/33 (153 days)	28/3/33 (179 days)
		Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity.	Total Amount.	Prevalence.	Intensity	Total Amount.	Prevalence.	Prevalence.	Pre-valence.	Pre-valence.	Pre-valence.
2·5	5	0	0	**0**	0	0	**0**	8	45	**4**	16	40	**6**	12	40	**5**	0	20	24	36	68
5·0	5	0	0	**0**	0	0	**0**	32	38	**12**	28	40	**11**	20	42	**8**	4	8	16	52	36
10·0	5	0	0	**0**	0	0	**0**	28	42	**12**	16	33	**5**	32	66	**21**	0	4	0	48	72
15·0	5	0	0	**0**	0	0	**0**	8	45	**4**	25	33	**8**	40	58	**23**	0	0	20	44	68
2·5	10	4	20	**1**	0	0	**0**	8	45	**4**	12	42	**5**	32	42	**13**	4	0	12	8	44
5·0	10	0	0	**0**	0	0	**0**	24	36	**8**	28	36	**10**	68	42	**29**	0	4	12	8	92
10·0	10	0	0	**0**	0	0	**0**	20	38	**7**	48	58	**28**	36	54	**20**	0	12	24	20	92
2·5	15	12	20	**2**	0	0	**0**	4	33	**1**	4	33	**1**	12	33	**4**	4	12	12	24	88
5·0	15	8	20	**2**	40	30	**12**	20	33	**6**	28	38	**11**	24	60	**14**	4	4	12	40	92
21·0	0	0	0	**0**	0	0	**0**	4	33	**1**	0	0	**0**	0	0	**0**	12	12	48	68	92

In an experiment of this nature the number of apples per sample is necessarily rather small, hence there are bound to be inherent differences between samples, however carefully they are prepared. The results should therefore be considered as a whole rather than individually.

(1) *Low-temperature Breakdown* (see Plate I, Fig. 1).

Inspection of Tables I to VI shows that low-temperature breakdown is encountered only at 34° F., the lowest of the three temperatures tested, and that its severity increases with increasing concentrations of carbon dioxide in the atmosphere and also with the duration of storage. The percentage of oxygen present appears to have had little effect upon the occurrence of this trouble. Low-temperature breakdown developed to some extent in the fruit stored in air in 1931-2, but not in 1932-3. The earlier season was also distinguished by the earlier development of breakdown under any conditions.

Broadly speaking, at 34° F. low-temperature breakdown sets a limit to the life of the fruit under any of the conditions of storage by the end of January. As regards the development of this disease none of the artificial atmospheres tested showed any advantage over air, but rather the reverse.

(2) *Brownheart* (see Plate II, Fig. 2).

Characteristic brownheart occurred at all three temperatures in the first season, but only at the highest temperature, 50° F., in the second season. As would be expected, no brownheart was observed in either season in the fruit stored in air. With 5 per cent. carbon dioxide present this disease developed only at the highest temperature (50° F.) and then only in the first season.

A difference in behaviour between the fruit of the two seasons was again brought out by the results obtained in the gas-mixtures containing 10 per cent. of carbon dioxide. Whereas in the first season there was a considerable amount of brownheart at 34° and at 50° F., but practically none at the intermediate temperature (39° F.), in the second season only a trace of this disease was observed under any of these conditions. With 15 per cent. of carbon dioxide brownheart was severe in both seasons.

The effect of the percentage of oxygen present is not clear, but it would appear that other things being equal, a low percentage of oxygen favours the development of brownheart. This disease may therefore be regarded as an effect of carbon dioxide. The fruit is most susceptible to brownheart at the highest of the three temperatures tested, and least susceptible at the intermediate one.*

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* A possible theoretical explanation of the comparative immunity of the fruit to brownheart injury at the intermediate temperature, based on the hypothesis that at lower temperatures the concentration of carbon dioxide in the tissue fluids may become excessive, whilst at higher temperatures the tissues may suffer from a lack of oxygen, is given in the first paper in this series (5, p. 36).

One important point that emerges from a consideration of the results with regard to brownheart is that it develops early in storage.

Considering the results of the two seasons together, the following conclusion, which is of practical importance, can be drawn. In the case of the Cox's Orange Pippin apple the risk of brownheart rules out the use of concentrations of carbon dioxide exceeding 5 per cent. at 34° F., or 10 per cent. at 39° F. At 50° F. there is a risk of damage from brownheart even with 5 per cent. of this gas.

(3) *Core-flush* (see Plate II, Fig. 3).

Although it is difficult to draw a clear line of distinction between the type of flesh browning, that is confined to the core-region of the fruit, and other types of flesh breakdown, it seems desirable in the case of the Cox's Orange Pippin apple to distinguish the former under the term core-flush. This trouble appeared to be more important as a cause of wastage in the second season than in the first, when it did not appear under any of the storage conditions in the fruit held at 34° F. In contrast to low-temperature breakdown and brownheart, more core-flush was found the higher the concentration of oxygen present, other things being equal, whilst carbon dioxide appeared to play no important part in its causation.

In the second season core-flush was completely absent from the fruit stored in air at 34° F. and traces only of this trouble were observed in air at the higher temperatures. The apples stored in the atmospheres containing 2·5 per cent. oxygen and 5 per cent. carbon dioxide both at 34° and at 39° F. were also found to be free from core-flush. The second season's results confirm those of 1931-2 in showing that core-flush increases with increasing concentrations of oxygen in the atmosphere. On the other hand, in the second season the evidence as to the possible effect of carbon dioxide was not clear since the fruit in all the gas-mixtures containing carbon dioxide, with the exception of that, as mentioned above, which contained the lowest concentrations of both oxygen and carbon dioxide, developed more core-flush than the control apples in air.

A consideration of the two seasons' results as regards wastage due to core-flush shows that an atmosphere containing 2·5 per cent. of oxygen and 5 per cent. of carbon dioxide either at 34° or at 39° F. is completely satisfactory.

(4) *Scald.*

The Cox's Orange Pippin apple, especially when wrapped in oiled paper, is one of the least susceptible to scald. No sign of this functional disease was observed throughout these investigations.

(5) *Fungal Wastage.*

Fungal wastage was extremely erratic in its occurrence and little obvious relationship could be found between its prevalence and the various atmospheric conditions tested. Broadly speaking, there was less fungal wastage in the fruit of the first season when only a negligible amount occurred at the lower temperatures. The results indicate that none of the gas-mixtures had an appreciable effect in retarding fungal rotting. Since, however, certain gas-mixtures are very effective in retarding ripening without causing any type of functional wastage it would appear that in the case of the Cox's Orange Pippin apple, at any rate, fungal wastage in gas-storage may present an important problem. A solution of this problem, which is obviously of great practical significance, is now being sought, the main lines of attack being (1) the use of wrappers treated with fungicides, (2) improved orchard hygiene, and (3) modified cultural practices aimed at producing a type of fruit that is resistant to fungal attack.

In concluding this section dealing with the various types of wastage met with in the course of these experiments, attention is again drawn to the marked differences exhibited by the fruit in the two seasons. The fruit used in the second season appeared, on the whole, to be markedly less susceptible to low-temperature breakdown and to brownheart, but more susceptible to core-flush and fungal rotting. The question arises as to how far these differences are to be attributed to an effect of season, maturity at gathering, or cultural conditions; unfortunately the data available do not provide an answer to this question.

The main conclusion of practical importance to be drawn from these wastage results is that for long-period storage all the atmospheres tested can be ruled out with the exception of that containing 2·5 per cent. oxygen and 5 per cent. carbon dioxide at 34° and at 39° F. and possibly that containing 2·5 per cent. oxygen and 10 per cent. carbon dioxide at 39° F.

CHANGE WITH TIME IN THE CONDITION (QUALITY) OF THE FRUIT.

The most obvious changes that take place in apples during storage are those which affect their flavour, colour, firmness of flesh, and loss in weight.

(1) *Flavour.*

Flavour is of the utmost importance in a dessert apple of good quality such as the Cox's Orange Pippin. Since there was some doubt as to whether the characteristic flavour of this variety would survive gas-storage treatment a special study was made in the 1932-3 season of the development of flavour in gas-stored fruit after a short period of conditioning in air at ordinary temperatures.

The first " flavour " test was carried out on January 30th, 1933, by a panel of eight persons. The apples had been removed from storage four days earlier and in the meantime had been held in air at an average temperature of 54° F. It was decided to limit the test to the apples at 39° F. because at this date very few samples of fruit from the other temperatures were sufficiently free from wastage. However, in order to provide a comparison with the cold-stored fruit, a sample from air at 34° F. was included in this test. Table VII summarizes the results obtained.

TABLE VII.

Flavour of Cox's Orange Pippin apples removed from storage on January 26th, 1933 (i.e. after four months' storage) and held subsequently in air at room temperature (54° F. av.) for four days.

Storage conditions.				Condition of the fruit as regards flavour, etc.
Temperature.		O_2 %	CO_2 %	
°F.	°C.			
39	4	2·5	5	Good flavour, unripe, normal, crisp, sweet.
39	4	5·0	5	Good flavour, rather unripe, normal, sweet.
39	4	10·0	5	Very good flavour, ripe, crisp, sweet.
39	4	15·0	5	Good flavour, ripe, normal, sweet.
39	4	2·5	10	Good flavour, unripe, normal, crisp, sweet.
39	4	5·0	10	Fair flavour, ripening, juicy, sweet.
39	4	10·0	10	Good flavour, unripe, normal, sweet.
39	4	2·5	15	Rather abnormal flavour, unripe.
39	4	5·0	15	Abnormal flavour, unripe.
39	4	21·0	0 (air)	Over-ripe.
34	1	21·0	0 (air)	Fair flavour, ripe, rather soft.

It will be seen from the above Table that the typical Cox's Orange flavour was preserved in many of the gas-mixtures. The apples stored in atmospheres containing 5 per cent. carbon dioxide with 10 or 15 per cent. of oxygen were ripe and of good flavour.* The fruit from the other gas-mixtures was unripe, and its flavour, with the exception of that stored in atmospheres containing 15 per cent. carbon dioxide, was normal. The apples stored in air at 39° F. were definitely over-ripe and inedible, while those stored in air at 34° F., although rather over-ripe, still retained a certain amount of flavour.

A further test was carried out with apples from the same samples on February 23rd. These apples had then been held in air at approximately 54° F. for four weeks after removal from storage. At this date most of the fruit, including that which had been cold-stored in air at 34° F., was either over-ripe and flavourless or possessed an unpleasant, abnormal flavour, and only three lots passed the "flavour" test. These had been stored in the atmospheres containing 2·5 per cent. oxygen + 5 per cent. carbon dioxide (excellent flavour) ;

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* If storage beyond January is not required, any of the gas-mixtures containing 5 per cent. carbon dioxide produces fruit of better quality than that obtainable in cold-storage in air. An atmosphere containing approximately 15 per cent. oxygen and 5 per cent. carbon dioxide can be obtained and maintained by the simple method of restricted and controlled ventilation, as at present practised commercially in the gas-storage of apples.

5 per cent. oxygen + 5 per cent. carbon dioxide (good flavour); and 2·5 per cent. oxygen + 10 per cent. carbon dioxide (fair flavour). The last mentioned were still firm and unripe.

The second "flavour" test was carried out on March 22nd, 1933, with the fruit stored under the few conditions which at this date had retarded ripening without causing undue wastage. The fruit had been removed from storage at 39° F. exactly three weeks previously. Apples stored in the atmosphere containing 2·5 per cent. oxygen + 5 per cent. carbon dioxide at 34° F. were included in this test because they were the only ones at this temperature which on the date of removal from storage possessed a normal flavour.

The results are presented in Table VIII.

TABLE VIII.

Flavour of Cox's Orange Pippin apples removed from storage on March 2nd, 1933 (i.e. after five months' storage) and held subsequently in air at room temperature (54° F. av.) for three weeks.

Storage conditions.				Condition of the fruit as regards flavour, etc.
Temperature.		O_2	CO_2	
°F.	°C.	%	%	
39	4	2·5	5	Full ripe, good flavour.
39	4	2·5	10	Ripe, very good flavour.*
34	1	2·5	5	Still unripe, fair flavour.

* On the actual date of removal from gas-storage the flavour of these apples was judged to be only fair. They were then in a rather unripe condition.

It will be seen that now the best apples were those stored at 39° F. in 2·5 per cent. oxygen + 10 per cent. carbon dioxide. Whilst the external appearance and firmness of flesh of the fruit stored at 34° F. in 2·5 per cent. oxygen + 5 per cent. carbon dioxide were such as to make these apples of excellent market quality, their flavour was judged to be only fair.

The third, and final, test was made on April 5th, i.e. over six months from the date of gathering. The apples had been removed from storage to room temperature eight days previously. The results were as follows (Table IX).

By this date (i.e. beginning of April) all the apples were either ripe or over-ripe. Those stored in 2·5 per cent. oxygen + 5 per cent. carbon dioxide at 34° F. and those stored in 2·5 per cent. oxygen + 10 per cent. carbon dioxide at 39° F. were firm and ripe, but only the latter possessed a good flavour.

The results presented above were confirmed in the following season (1933-4). A flavour test conducted, as before, but with a panel of over a dozen persons,

TABLE IX.

Flavour of Cox's Orange Pippin apples removed from storage on March 28th, 1933 (i.e. after six months' storage) and held subsequently in air at room temperature (54° F. av.) for one week.

Storage conditions.				Condition of the fruit as regards flavour, etc.
Temperature.		O_2	CO_2	
°F.	°C.	%	%	
39	4	2·5	5	Full ripe, fair flavour.
34	1	2·5	5	Ripe, firm, fair flavour.
39	4	2·5	10	Ripe, firm, good flavour.

showed that after six months' storage, and a further week in air at room temperature, the apples that had been stored in 2·5 per cent. oxygen + 5 per cent. carbon dioxide at 37·5° F. were in by far the best condition as regards consistency and flavour. Those stored in 2·5 per cent. oxygen and 10 per cent. carbon dioxide at the same temperature were also judged to be of good flavour. The fruit that had been cold-stored in air at 34° F. was by this time, of course, over-ripe and quite unfit to eat. It is worth noting that this season's results also showed that the quality of the fruit gathered in the more mature condition far exceeded that of the less mature fruit as regards both appearance and flavour, but not as regards actual wastage.

The results of these " flavour " tests have therefore brought out the important point that under the best gas-storage conditions tested the development of the characteristic flavour of the fruit is retarded, but is not destroyed. In other words, although apples eaten immediately after removal from gas-storage may have little flavour, the full flavour is developed after the fruit has been kept in air at ordinary room temperature for a few days.

They have also shown that only at the intermediate temperatures (37·5° and 39·5° F.) did the fruit develop its characteristic flavour after long periods of gas-storage. At these temperatures, full flavour was, with one exception (2·5 per cent. oxygen + 10 per cent. carbon dioxide), never attained in atmospheres containing more than 5 per cent. carbon dioxide. Since full flavour is developed when the fruit becomes ripe, it follows that the maximum storage life will be obtained in those gas-mixtures which most effectively retard the ripening of the fruit without causing any functional disorder. This gas-mixture is the one containing 2·5 per cent. oxygen + 5 per cent. carbon dioxide.

(2) *Change in Ground-colour.*

The ground-colour of the Cox's Orange Pippin apple ranges from apple green, on the tree, to light cadmium yellow, when the fruit is very over-ripe and senescent. This colour range in Ridgway's series is from No. 29′ to No. 18, the corresponding numbers in the classification of colours used at the Ditton Laboratory being Nos. 2 to 15. At the normal time of gathering the ground-colour of the fruit used in these experiments was dull green yellow (our No. 5). When ripened in air the ground-colour of the ripe fruit ranged from Chalcedony yellow (No. 7 in the Ditton series) to Strontium yellow (No. 8 in the Ditton series). As will be seen from Table X in which the ground-colour of the cold-stored fruit at the end of its commercial storage life at 39° F. (mid-December) is compared with that of gas-stored fruit on the same date, the retardation of the change in colour was in every case greater in gas-storage than in cold-storage.

TABLE X.

Condition of cold-stored and of gas-stored Cox's Orange Pippin Apples at the End of the Commercial Storage Life of the Former (14/12/32, *at* 39°*F.*).

Storage conditions.				Condition of the fruit on 14/12/32 (i.e. after eleven weeks' storage).		
O_2 %	CO_2 %	Temperature.		Flavour.	Ground-colour.*	Firmness of flesh lbs. pressure.*
		°F.	°C.			
2·5	5	39	4	Unripe, normal, good	6·5	7·5
2·5	10	39	4	Unripe, normal, good	6·5	9·0
5·0	5	39	4	Unripe, normal, good	6·5	6·5
5·0	10	39	4	Unripe, poor	6·5	8·0
10·0	5	39	4	Ripening, good	6·5	6·5
10·0	10	39	4	Unripe, normal, fair	6·5	7·0
15·0	5	39	4	Ripening, very good	7·0	6·0
21·0	0 (air)	39	4	Ripe, good	7·5	6·0
21·0	0 (air)	34	1	Ripening, good	7·0	6·5

* See text.

The retention of their green ground-colour over very long periods is one of the chief characteristics of gas-stored apples. This point is well brought out by the fruit which was gas-stored at 39° F. in the atmosphere containing 2·5 per cent. oxygen + 5 per cent. carbon dioxide. The fruit stored under these conditions, which, as pointed out above, was the best as regards wastage and flavour, showed less change in ground-colour at the end of its commercial storage life (i.e. after more than five months' storage) than the controls in air had shown approximately three months earlier.

From an analysis of the influence of the three variables, temperature, concentration of oxygen, and concentration of carbon dioxide, on the progress of change in ground-colour of the Cox's Orange Pippin apple, the following conclusions may be drawn. The effect of temperature is pronounced, the higher the temperature the more rapid the yellowing, both in the artificial atmospheres and in air. As stated above, the change in ground-colour of the fruit in all the artificial atmospheres showed more retardation than that of the control fruit in air. This result is to be attributed not only to an effect of carbon dioxide, but also to an effect of oxygen, the lower the concentration of oxygen in the atmosphere, the greater the retardation of the change in ground-colour.

(3) *Change in Firmness of the Flesh.*

Periodic determinations of the firmness of the flesh of Cox's Orange Pippin apples have shown that in general the gas-stored fruit is considerably firmer on any given date than corresponding fruit stored in air (Table X). From an analysis of the results it appears that the retardation of softening is mainly to be attributed to the carbon dioxide. Subnormal concentrations of oxygen alone appear to have little or no effect ; nevertheless, when carbon dioxide is present they appear to accentuate the retarding effect of this gas. Figure 1 brings out these points. It is of interest to note from this Figure that the apples after about seven months' storage at 37·5° F. in an atmosphere containing 2·5 per cent. oxygen and 10 per cent. carbon dioxide, were as firm as on the date of gathering.

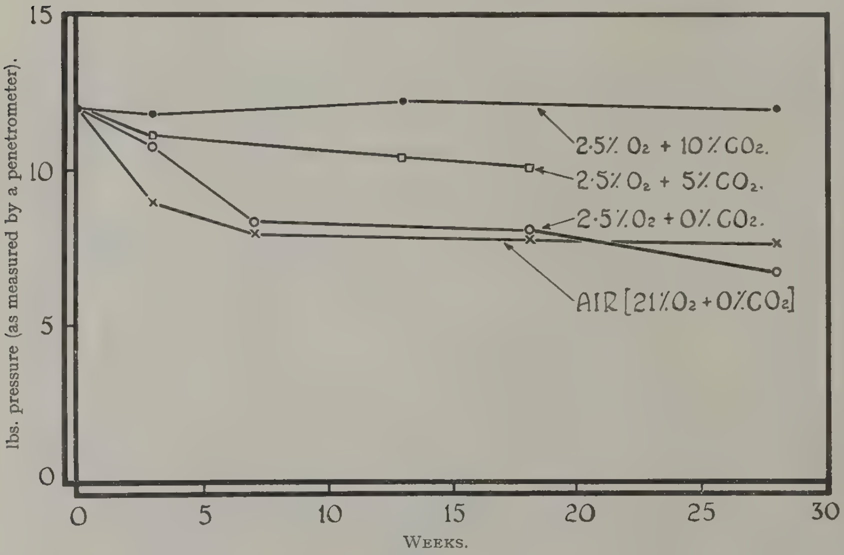

Fig. 1.—Effect of carbon dioxide and of oxygen on the softening of Cox's Orange Pippin apples in storage at 37·5° F. (3° C.).

(4) *Loss in Weight.*

The effect of the storage conditions upon the loss in fresh weight of the fruit was determined for one temperature (39° F.) in the 1931-2 season. The results are given in Table XI.

TABLE XI.

Percentage Loss in Weight of Cox's Orange Pippin Apples stored at 39° *F.* (1931-2).

Gas-mixture.		Percentage loss in weight.				
O_2 %	CO_2 %	2/12/31	13/1/32	29/2/32	20/4/32	Average per 100 days.
2·5	5	1·14	1·99	2·62	3·84	1·78
2·5	10	1·30	2·08	2·71	3·17	1·80
2·5	15	1·30	2·04	2·69	3·85	1·87
5·0	5	1·21	2·32	3·14	3·81	1·96
5·0	10	1·49	2·28	2·91	4·03	2·05
5·0	15	1·56	2·12	2·84	4·02	2·03
10·0	5	1·48	2·37	3·22	4·71	2·20
10·0	10	1·62	2·30	3·10	4·51	2·19
10·0	15	1·52	2·32	3·05	4·46	2·14
21·0	0	1·72	2·87	3·66	5·07	2·52

NOTE.—The weighings on the various dates were made on different samples.

The results show that the smallest loss in weight occurred in the atmospheres containing the lowest concentrations of oxygen, namely 2·5 per cent., and the greatest loss took place in air, i.e. with 21 per cent. of oxygen present. Little, if any, effect of the concentration of carbon dioxide in the atmosphere was observed. The greatest difference in loss in weight observed, namely that between the apples stored in air and those stored in 2·5 per cent. oxygen and 5 per cent. carbon dioxide, can adequately be accounted for by assuming that the loss of carbon (in respiration) was reduced from a value of about 40 c.cm. per 10 kg. hr. in the former case to about 20 c.cm. per 10 kg. hr. in the latter. This assumption is based upon data previously recorded (3) on the effects of carbon dioxide upon the rate of loss of the carbon-containing constituents of the apple fruit by oxidation to carbon dioxide.

It is interesting to note that the loss in weight of the gas-stored fruit on the 29th of February was less than that of the cold-stored fruit on the 1st of January.

SUMMARY.

Within the limits of the conditions tested in these experiments *the maximum storage life of Cox's Orange Pippin apples was obtained at* 39° *F. in an atmosphere containing* 2·5 *per cent. of oxygen and* 5 *per cent. of carbon dioxide.* Fruit stored under these conditions will develop its full characteristic flavour after a short conditioning period in air at ordinary temperatures.

These atmospheric conditions cannot be obtained by the simple method of restricted and controlled ventilation, which is applicable only when the concentrations of oxygen and carbon dioxide desired add up to 21 per cent., the concentration of the former in ordinary air. Some means of absorbing the excess carbon dioxide in the storage atmosphere is therefore necessary (see Appendix).

In conclusion the writers wish to acknowledge the valuable assistance of Mr. G. H. Crouch throughout these investigations.

APPENDIX.

Whilst the object of this paper is to demonstrate the most suitable storage conditions for the storage of the Cox's Orange Pippin apple and not to deal with the various methods of obtaining such conditions, any information on the latter subject, that may serve as a guide to prospective owners of gas-stores will obviously serve a useful purpose. A considerable amount of exploratory work on the design and operation of a scrubbing system for removing the excess carbon dioxide from gas-stores for fruit requiring an atmosphere containing low concentrations of both oxygen and carbon dioxide has been successfully carried out. The principle of a method consisting of a simple scrubber, using a solution of caustic soda, and carefully controlled ventilation, is fully described elsewhere (7).

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(*Received* 12/8/36.)

Plate I.

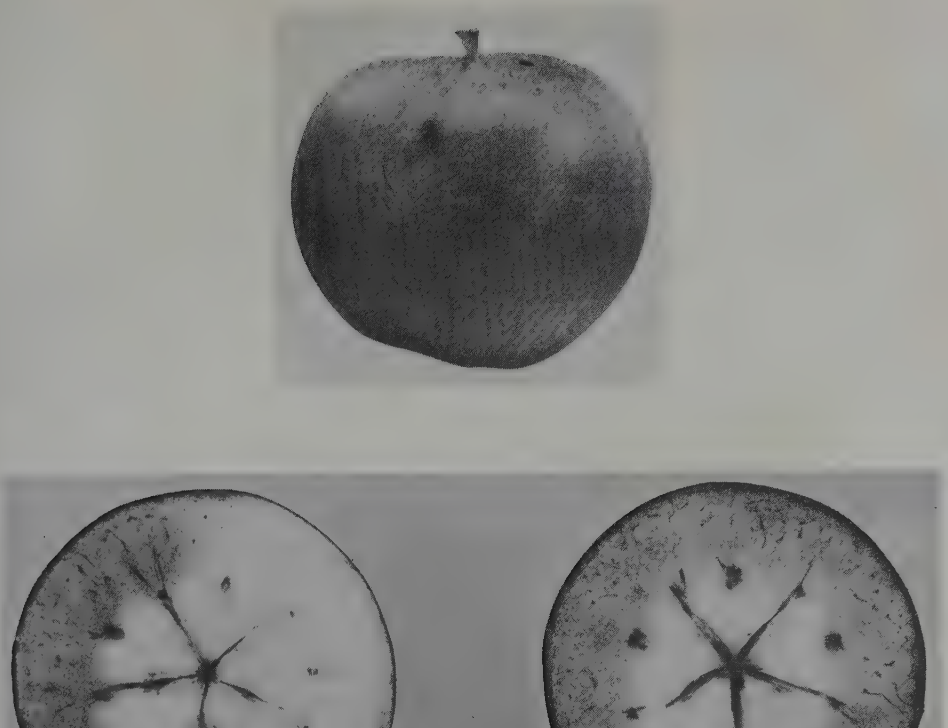

Fig. 1.

Above: External appearance of a Cox's Orange Pippin apple showing severe low-temperature breakdown.
Below: Three stages of low-temperature breakdown in Cox's Orange Pippin apples.

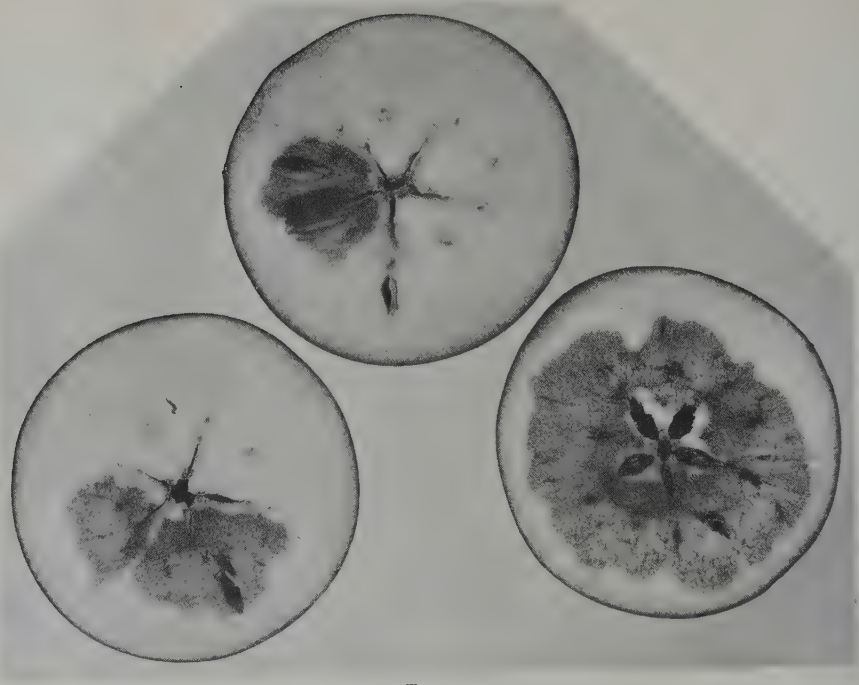

FIG. 2.
Brownheart in Cox's Orange Pippin apples.

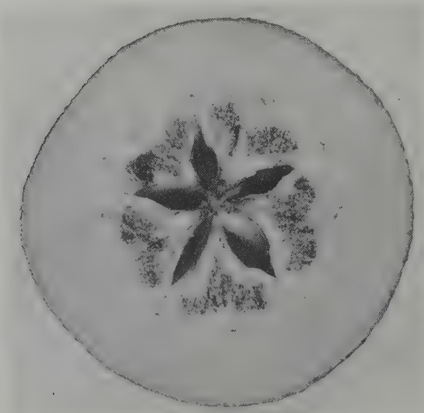

FIG. 3.
Cox's Orange Pippin apple showing core flush.

BOOK REVIEWS

THE APPLES OF ENGLAND. By H. V. TAYLOR. (Crosby Lockwood & Sons. 21s.)

Since Hogg's great work on British fruits no such comprehensive work as Mr. H. V. Taylor's *The Apples of England* has been published. There are other books on fruit of later date than Hogg's, but they are on different lines to Mr. Taylor's. To understand the aim and object of his book it is necessary carefully to read the foreword by Sir Daniel Hall and the author's preface. The author does not claim to give a complete list of all the varieties of apple that can be found under various names growing in the British Isles, but he certainly has compiled a very wonderful descriptive catalogue of varieties all of which are now growing somewhere and have been handled by the author.

The book is in two parts, of which the descriptive list forms Part II. One could wish that the author had given his readers a little more in Part I, for what he has given is excellent and most informative. A short chapter on diseases and pests together with the most approved modern spraying treatments would have added to the value without adding unduly to the size of the volume or its cost. Such information may not be required by the commercial grower of to-day but it is still urgently needed by some amateurs and their gardeners.

In a very few years a second edition will be wanted to bring Part II up to date with particulars of the many varieties now under trial in the National Trials. We must hope that it will be found possible to expand Part I without reducing Part II.

Most readers will probably spend more time studying Part II than Part I. This descriptive list is most fascinating reading, and the work entailed in compiling it must have been enormous though there are no superfluous words in it. For many years to come this Part II will be the standard work of reference for all growers, commercial or amateur.

For the amateur, or Sir Daniel Hall's " fancier ", the book is quite indispensable. He can find much of interest in just reading its pages and he can certainly obtain all the necessary information about any variety, old or new, that he wishes to try in his garden. Thanks to the letters N.L. he learns whether his fancy can be bought from the trade or must be sought for among kind friends with similar interests to his own. These two letters show that many varieties highly regarded in their day have been discarded, probably for good reasons, but perhaps in some cases without due consideration for certain qualities that the commercial fruit grower cannot or will not recognize.

When one finds in the catalogue of Part II the name " Leather Coat " one wishes that the trees referred to in Part I could be definitely associated with the period of Shakespeare. But perhaps Shakespeare was not too accurate in his nomenclature as, according to Mr. Taylor, the Pippins were only introduced into England about 1500 and yet the poet makes Justice offer to Sir John Falstaff " a pippin of mine own graffing ". King Henry IV died in 1423.

The book is well got up in every way. The paper is good, the printing clear, the illustrations accurate and the index sufficient. It has been published at a time when the amateur's interest in his garden was never greater, and when the country is being urged to produce as much as possible within itself. Everyone who grows apples, whether for pleasure or profit, should possess this book and study it. Having read it he will be grateful to Mr. Taylor for putting so much valuable and interesting information in such a readable form and in such a comparatively small compass.

C.G.A.N.

THE SCIENTIFIC PRINCIPLES OF PLANT PROTECTION WITH SPECIAL REFERENCE TO CHEMICAL CONTROL. By HUBERT MARTIN, D.Sc. (Pp. xii. + 379. Edward Arnold & Co. Second Edition, 1936. 21s. net.)

Eight years ago Dr. Hubert Martin published *The Scientific Principles of Plant Protection*. The very favourable reception that the book received, together with the rapid advances in our knowledge of the theory and practice of Plant Protection, has induced the author to bring his subject matter up to date in a new edition, adding to the title, " *with Special Reference to Chemical Control* ".

The present book follows the same general plan of the former edition except that the chapter on Biological Control occupies a more natural position, following that on " The External Factors on the Susceptibility and Liability of the Plant to Attack ", instead of coming towards the end of the book after the chemical aspects of the subject have been treated. As stated by the author in his preface, " Every phase of the subject has developed in the eight years since the first edition appeared " so that, " The inclusion of new material has necessitated a drastic revision and, except for the Introductory chapter, the book has been rewritten and has had to be reset for this, the second edition."

The result is that this edition, containing sixty odd pages more than the original, is more than ever a standard work of reference for all who are interested in the modern methods directed towards protecting plants from the numerous pests and diseases to which they are subject. It may seem presumptuous, therefore, to ask for more, but we should like to see bacterial diseases of plants treated more fully. These are becoming more and more important and some at any rate yield to chemical treatment, e.g. *Pseudomonas juglandis* and *Bacillus amylovorus*. From a glance through the index it would appear that only three such diseases are referred to at all, though it will be found that a few others are mentioned in the text, and it is a matter of some regret that the index is far from complete in other respects. One curious slip appears in two places in the index where " Graft Hybridization " is used in reference to methods of " top working " fruit trees as a control measure against Fire Blight.

The progress made in the last eight years is perhaps best illustrated by Chapter V, "Fungicides and Insecticides", which deals chiefly with those accessory substances designed to improve the spreading and sticking properties of spray fluids in order to render more effective the lethal constituents present. We here find discussed the Sulphonated Alcohols, the Agrals, and a number of proprietary substances not mentioned in the first edition. The study of such substances will probably prove of increasing importance in relation to the modern demand for " Combined Washes ".

To those who are familiar with the former edition further recommendation is unnecessary ; all others who are interested in growing ornamental and crop plants should take an early opportunity of consulting this book.

AGRICULTURAL BOOKS. (Baillière, Tindall & Cox, London. Free.)

A list of books and periodicals comprising all current books dealing with Agricultural Science, Horticulture, Forestry and Animal Husbandry.

This publication, containing a subject index and three sections dealing with Agriculture, Horticulture and Forestry ; Animal Husbandry ; and Periodicals, is useful to the research worker. Some important volumes published ten or fifteen years ago, which are not met with every day but should be in every library, are catalogued as well as the latest editions and additions. The list of periodicals, if incomplete, is useful.

THE JONES-BATEMAN CUP FOR RESEARCH IN FRUIT-GROWING

In 1920 Miss L. Jones-Bateman of Cae Glas, Abergele, presented to the Royal Horticultural Society a valuable silver-gilt replica of the Warwick Vase to be used for the encouragement of fruit production. It is accordingly decided to offer it triennially for researches in the growing of hardy fruits, figs, grapes and peaches in the open or under glass, and it is available for award in 1936.

Candidates should submit accounts of their work by October 31st. The work dealt with must have been carried out by the candidate in the United Kingdom mainly during the past five years. The Cup will be held for three years by the successful candidate who must give a bond for its safe return, and when the Cup is relinquished the holder will receive a commemorative gold medal. The holder will be eligible to compete on the next or any succeeding occasion.

The Assessors will be three, two appointed by the Royal Horticultural Society and one by the National Farmers' Union, and they will report to the Council of the Royal Horticultural Society upon the originality and comparative potential value to the fruit-growing industry of the work of the candidates.

The Council of the Royal Horticultural Society will award or withhold the Cup at its discretion.

F. R. Durham, *Secretary.*

PEST CONTROL PRODUCTS AND AMALGAMATION OF INTERESTS

A development of the first importance to gardeners and the growers of fruit and field crops is foreshadowed in an announcement that Imperial Chemical Industries and Cooper, McDougall & Robertson are arranging to pool their resources in the manufacture and distribution of insecticides and fungicides for the control of pests and diseases on plants. The object of this co-operation is to enable the two companies to offer a wider range of products and a more extensive service to the public. The arrangements will make available to Cooper, McDougall & Robertson, who have for many years been one of the leading companies in this trade in the British Empire, the very large productive capacity of the I.C.I. factories. It will further result in the pooling of the research work carried on by I.C.I. in their chemical laboratories and at their biological station at Jealotts Hill, and also the field research carried out by Cooper, McDougall & Robertson at Yalding.

RECENT ADVANCES IN THE WORK ON REFRIGERATED GAS-STORAGE OF FRUIT

By F. KIDD
Low Temperature Research Station, Cambridge
and
C. WEST
Ditton Laboratory, East Malling, Kent

DEVELOPMENT OF THE GAS-STORAGE METHOD IN GREAT BRITAIN.

THE work of the Food Investigation Board during the years immediately after the War showed that for many varieties of English apples cold-storage in ordinary air was impracticable, the reason being that the fruit when kept for considerable periods at temperatures in the region of 34° F. developed a functional disease to which the name "low-temperature breakdown" was given. This disease is a particularly serious one, because it may develop rapidly during the marketing and distribution of apples that appear to be in perfect condition on removal from store. Previously, the trade had been unable to explain why cold-stored fruit was so often poor in quality and difficut to market, and the fact that mechanical refrigeration was used for only a very small proportion of the total quantity of apples grown in this country is clear evidence of the lack of confidence in the cold-stored product. In fact, in 1918, there was only a single cold-store owned and run by a grower, although the need and advantages of long-period storage for apples were fully realized by all concerned. To meet this demand for a storage method that would replace ordinary cold-storage, especially for those kinds of apples that were known to be susceptible to low-temperature breakdown, the gas-storage method was devised and developed.

PRINCIPLE OF THE METHOD.

The main feature of gas-storage is control of the composition of the atmosphere in the store. Although temperatures that are above the danger limit for the fruit are used, mechanical refrigeration is essential, hence the method is more accurately described as "refrigerated gas-storage".

Experiments with many varieties of home-grown apples have shown that in an atmosphere containing more carbon dioxide and considerably less oxygen than normal air, the life of the fruit is greatly prolonged and its firmness and green ground-colour are retained to a remarkable degree.

Fruit, being living material, continually absorbs oxygen from the air and gives off an approximately equal volume of carbon dioxide, the process, in fact being analogous to the respiration of animals. It follows, therefore, that the atmosphere of any closed store containing fruit must always contain less oxygen and more carbon dioxide than normal air, to a degree that will depend on the gas-tightness of the store, the quantity and the temperature of the fruit stored, and also, but usually to a less extent, upon the nature of the fruit (variety, maturity when gathered, etc.). It is obvious that if control of the storage atmosphere is required, a more or less gas-tight chamber is essential.

SIZE OF CHAMBER.

The limits to the size of the individual storage unit are set by the speed at which the grower can fill it with fruit (see page 308) on the one hand, and by such economic considerations as the ratio between the capacity of the store and the size of the refrigerating plant etc. on the other. In this country a chamber having a capacity of from forty to fifty tons has proved satisfactory under commercial conditions.

CONSTRUCTION OF A GAS-TIGHT CHAMBER.

The method generally adopted to make a chamber gas-tight is to line its roof and walls with tinned or galvanized sheet steel of about 26 s.w.g. The metal sheets are nailed or screwed to wooden grounds with an overlap of 2 or 3 in., the overlapping joints being sealed by inserting vaseline or some other suitable material before they are fastened together. As a rule, the metal sheeting, in addition to being galvanized, is treated back and front with a dressing of anti-corrosive oil or bitumastic paint.

The floor is usually of concrete. Its surface is gas-proofed by coating it with vaseline or with a proprietary composition that has the additional advantage of forming a firm, smooth surface that facilitates thorough cleansing each season before loading.

For convenience in loading, and to ensure loading to capacity, the door should extend to the full height of the chamber. It has been the usual practice to make this door in two or more vertical sections. These may be of 5-ply wood, metal-covered on both sides, screwed down to wooden door-frames, the joints being sealed with a substance similar to that used for sealing the metal sheeting. A lightly-insulated outer door is useful, but not essential.

Gas-stores are never completely gas-tight ; in fact the best store that has been tested showed a leakage amounting to about 6 per cent. of its volume per day. Leakage of this order is no disadvantage, since it makes only a negligible difference in the time taken to build up the concentration of carbon dioxide required, after which ventilation must, of course, be given.

Strong winds may cause a serious loss of gas, and it is therefore advisable to build the store on the leeward side of the packing-shed or of whatever shelter may be available. While metal linings have so far been preferred in Great Britain, experiments reported from Canada show that special forms of plaster, with surface dressings, have been very efficient in rendering chambers gas-tight. In S. Africa a gas-store for fruit, having a capacity of 150,000 cu.ft., has been constructed on quite a different principle. The gas-tight shell of welded steel construction is outside the insulation, which consists of pumice concrete in the form of cell concrete. The building is supported by steel columns and joists welded to the gas-tight shell in such a way that provision is made for expansion and contraction of the shell under the influence of changes in temperature.

SECURING THE CORRECT ATMOSPHERE IN THE STORE.

It has already been mentioned that the principal gases to be controlled are oxygen and carbon dioxide, and that the latter is derived from the former, approximately volume for volume, by the respiratory activity of the fruit.

For some varieties of apples (e.g. Bramley's Seedling) the correct concentrations of oxygen and carbon dioxide are such as can be produced by allowing the carbon dioxide emanating from the fruit to replace oxygen in the air, and by controlling its concentration by restricted and regulated ventilation with fresh air. In this way the excess of carbon dioxide is replaced, as required, by oxygen in the admitted air, and the sum of the concentrations of oxygen and carbon dioxide always amounts approximately to 21 per cent. (i.e. the concentration of oxygen in normal air), the remaining 79 per cent. consisting, of course, almost entirely of the inert gas nitrogen. It is therefore necessary to pay attention to and record the concentration of carbon dioxide only, and to control the composition of the air in the store with the aid of this record. With this very simple method of operating the store, separate control of the concentrations of both oxygen and carbon dioxide is not possible.

VENTILATION.

For a 50-ton chamber a single adjustable port-hole, about 1 ft. square, placed either in the door or in one of the walls, is more than sufficient for ventilation. An opening of this size is, however, useful because it enables the grower to inspect the fruit and to withdraw samples for examination. Two ventilators at different levels set up a through draught, and act much more rapidly than a single opening.

INDEPENDENT CONTROL OF OXYGEN AND CARBON DIOXIDE.

Control of carbon dioxide and of oxygen by restricted and regulated ventilation alone will, as already pointed out, provide the required atmosphere only when the sum of the concentrations of these two gases reaches 21 per cent.

For other mixtures, such as 3 per cent. of oxygen + 5 per cent. of carbon dioxide, that give the best results for several varieties of apples, means of absorbing the excess of carbon dioxide in the chamber are required.

Chemical absorption of the excess of carbon dioxide is employed, the process being controlled, either by regulated circulation of the storage atmosphere over a quantity of the absorbent, or by introducing limited charges of the absorbent into the chamber at intervals, as required. The absorbents at present employed are caustic soda and milk of lime.

SECURING THE CORRECT TEMPERATURE IN THE STORE.

The capacity of the refrigerating plant should be sufficient to reduce the temperature of the fruit from 65° F. to 40° F., with an external temperature of 70° F., in four to five days after the closing of the chamber. From the point of view of preservation, the more rapidly the fruit is cooled to the correct storage temperature after gathering, the better.

Two main methods of arranging the cooling surface, i.e. the cooling pipes or grids within the chamber, have been employed. In one, the cooling pipes are attached to the roof, with gutters fitted underneath to catch condensed water. In the other, the pipes are arranged in a central tower or duct through which air is drawn by a fan, usually designed so that the flow can be reversed periodically. The fan is driven by a motor, usually placed outside the chamber for accessibility and to avoid unnecessary heating. Leakage of gas along the spindle is prevented by a gland, which must be carefully designed, since any leakage at this point is serious on account of the pressure generated by the fan. Forced air circulation facilitates uniform and rapid cooling of the fruit.

HUMIDITY OF THE ATMOSPHERE IN THE STORE.

Control of the humidity of the atmosphere in gas-stores for apples has so far not been found necessary. Under commercial conditions the relative humidity appears to vary between 85 per cent. and 98 per cent. of saturation.

INSTRUMENTS REQUIRED.

Thermometers. For the successful running of a gas-store for fruit, it is essential to have an accurate record of the actual temperature of the fruit. For this purpose it is desirable to have at least three distant-reading electrical or mercury-in-steel thermometers which should be placed amongst the fruit inside the boxes or trays.

Gas Indicators. In a large gas-store consisting of a number of chambers it is advisable to have an instrument that will quickly indicate the composition of the storage atmosphere. When the concentration of carbon dioxide alone is required the katharometer, which indicates the percentage of this gas on a galvanometer scale, has been adapted for use in gas-stores. For gas-stores in which independent control of oxygen and carbon dioxide is required, an instrument has recently been designed which will quickly indicate the percentages of both these gases.*

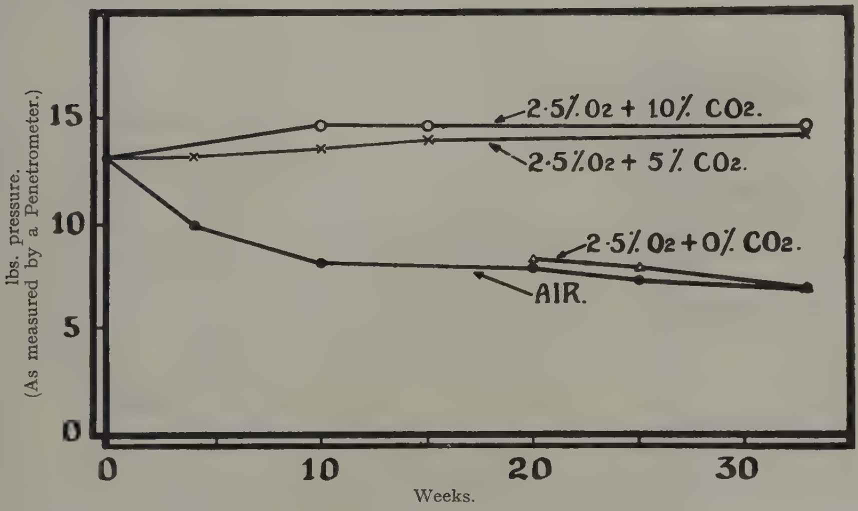

FIG. 1. Effect of carbon dioxide and of oxygen on the softening of King Edward VII apples in storage at 37.5° F.

Note.—After 33 weeks' storage the apples in the atmospheres containing carbon dioxide were firm, mainly green and showed practically no wastage; those stored in air, on the other hand, were mealy, yellow and showed 76 per cent. wastage.

ADVANTAGES OF GAS-STORAGE OVER ORDINARY COLD-STORAGE.

For certain varieties of apples gas-storage has many advantages over cold-storage in air. The more important of these are as follows:—

(1) The ripening of the fruit at any given temperature is slowed down to about half the rate in air at that temperature; the life of the fruit in store is accordingly twice as long.

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* *Smith, A. J. M.*, and *Gane, R.*: Measurement of Temperature and Gases. Suggested Combined Apparatus for Refrigerated Spaces. "Ice and Cold Storage," Vol. 38. August and September 1935, p. 128.

(2) Trouble from low-temperature breakdown is avoided because the temperatures used are above the limit at which this disease will develop.

(3) The firmness of the fruit is preserved almost unchanged over long periods of storage (Fig. 1).

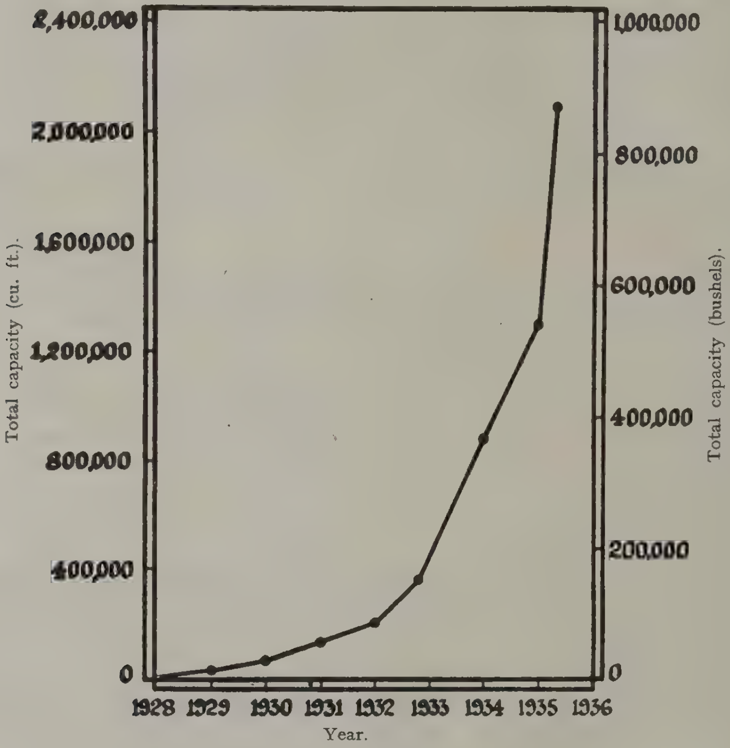

FIG. 2. Increase in the capacity of gas-stores for fruit in England.

(4) The change in ground-colour from green to yellow is markedly retarded. The apples for which the charts in Fig. 1 were made were found, after thirty-three weeks' storage in the atmospheres containing carbon dioxide, to be firm, mainly green, and showing practically no wastage, whereas those stored in air were mealy, yellow and showed 76 per cent. wastage.

(5) The surface-eating Tortrix moth larvae that may cause so much damage to apples in cold storage, not only directly by the lesions produced in the skin,

but also indirectly by facilitating infection by rot-producing fungi, are quickly killed in gas-storage.

(6) The life of the apples after removal from gas-storage is remarkably long. From the point of view of the distributor and consumer this is perhaps the most important advantage of gas-storage.

In view of these considerations it is not surprising that commercial gas-storage of apples has been very rapidly taken up by growers in this country, so far with most gratifying results. The rate of development of commercial gas-storage for apples in England is shown in Fig. 2, which gives the total capacity of gas-stores from 1929 to January 1936. It will be seen that the total already exceeds two million cubic feet. During the last few months the capacity has been increased by approximately 800,000 cubic feet, which, expressed as weight of fruit stored, represents rather more than 6,500 tons. It is interesting to note that part of this storage space is intended for the gas-storage of pears.

The success of the industry in developing this new method of storing fruit can be attributed mainly to the fact that the commercial application of gas-storage of apples has invariably been preceded by scientific laboratory experiments and storage trials on a semi-commercial scale. Gas-storage trials with apples are now being carried out in Canada and in the United States of America. From results already published it would appear that the gas-storage method can be used with advantage for the McIntosh and Yellow Newtown varieties of apples as grown in Canada and California respectively.

NORMAL BEHAVIOUR OF APPLES AFTER GATHERING: THE CLIMACTERIC.

The theoretical aspects of refrigerated gas-storage for fruit are still in their elementary stages of development. Fruits of all kinds are highly organized physico-chemical systems, the characteristics of which are those of living systems, namely, intake of food, growth, maintenance of essential structure, performance of work and excretion of end-products. The problems involved are fundamental problems of biology and are still far from solution.

Advance on the descriptive side of fruit behaviour has been much easier and therefore has been much more rapid. During the development of a fruit a sequence of changes occurs which, in its broad outline, is characteristic of the species and is pre-determined. Taking, for example, an apple; from its microscopic beginnings in the bud stage to a point of time some two or three weeks after petal-fall, when its size is between that of a hazelnut and a walnut, the cells of the flesh are continually dividing. In other words growth during that period is by cell multiplication. During the next two to three months, while the apple is enlarging, each of the fifty million or so cells present in it increases in size and stores up carbon in the form of sugars and acids. With the coming of autumn and leaf-fall, growth in size of the apple tends to come to a standstill. Its source of food supply is cut off, and sooner or later it will separate naturally from the tree. The change that occurs about this time is a profound and vital one and has been called the *climacteric*. The living fruit now loses its capacity to build up and keep in repair its essential structure. Henceforth, while stored food is consumed, oxygen taken up, carbon dioxide evolved, heat produced and cell turgor maintained, the wear and tear on the machine is not made good.

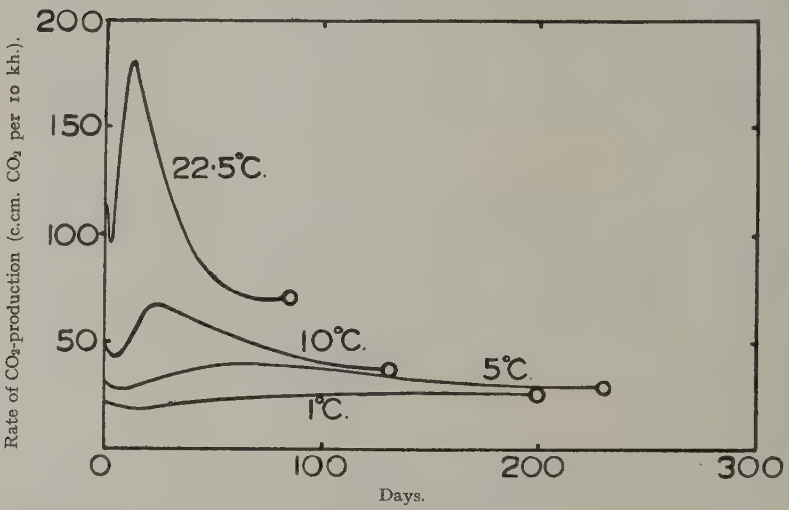

FIG. 3. Effect of Temperature.

Man, in gathering the fruit, interrupts this sequence at the time when growth is nearly complete, but just before the onset of the climacteric. After gathering, the course of events includes a change in ground-colour of the skin from green to yellow, and a softening and sweetening of the flesh which eventually becomes insipid and mealy. The chemical changes are: first, a rapid loss of starch, by conversion to hexose sugars; secondly, a temporary increase, followed by a steady loss, of cane sugar (saccharose); thirdly, a steady loss of acid; fourthly, an increase in the protein whilst the total nitrogen remains constant; and lastly, an initially small but rapid loss of cell-wall material, followed by its steady decrease. Loss of water and carbon dioxide goes on continuously as does also the uptake of oxygen.

THE EFFECT OF TEMPERATURE.

The intensity of respiration, as shown by the rate of production of carbon dioxide, provides a very convenient index of the physiological and chemical changes going on in the fruit. This is illustrated in Fig. 3, which shows how the rate of carbon dioxide-production at various temperatures changes with time, for an apple gathered at the normal time and kept in air. The climacteric change is accompanied by a rise in activity.

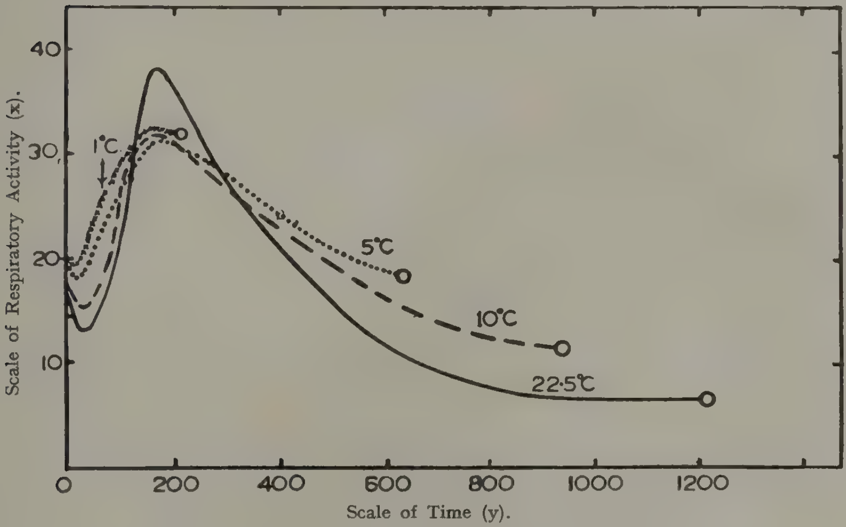

FIG. 4. Effect of Temperature.

Coefficients for	1° C.	5° C.	10° C.	20° C.
x scale	× 1·00	× 1·50	× 2·35	× 5·75
y scale	× 1·00	× 0.36	× 0·12	× 0·07
1/y	× 1·00	× 2.80	× 8·30	× 15·00

[Time in days: Resp. Activity in c.cm. per 10 kh.: 1/y a function of ripening activity.]

Fig. 4 deals with the same set of results in a different way. It will be seen from this figure that the sequence of changes has the same general character at all temperatures, although differences in detail occur.

THE EFFECT OF CARBON DIOXIDE.

The broad effect of carbon dioxide in the atmosphere, as in gas-storage, upon the metabolic activity of the apple is illustrated by Fig. 5. This figure shows the result of keeping the fruit from the time of gathering in an atmosphere containing carbon dioxide. The climacteric is suppressed or postponed.

It is of the utmost importance that the significance of this point should be fully appreciated by the grower. The beneficial effect of the carbon dioxide in the storage atmosphere is, to a large extent, lost if the fruit has reached the climacteric before it is gas-stored. It is obvious, therefore, that grave risk is taken when fruit is allowed to reach maturity on the tree, or when there is considerable delay in storing the fruit. Not more than five days should elapse between picking the fruit and sealing the gas-store containing it.

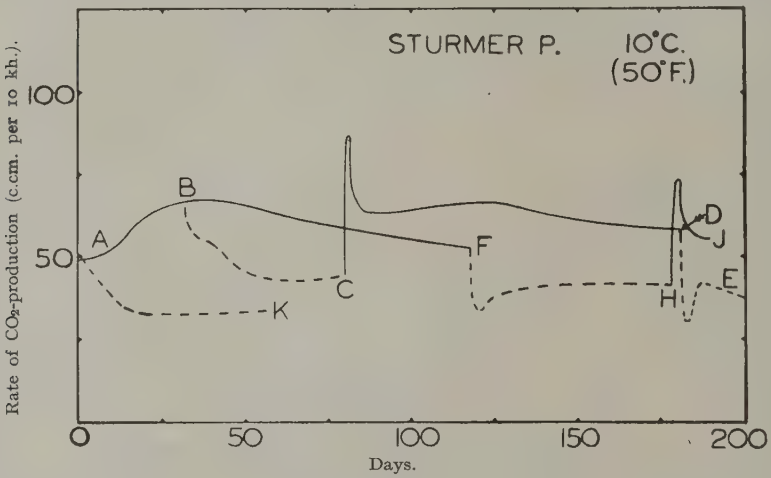

FIG. 5. Effect of CO_2.

Set I. Apples in 10% carbon dioxide from the outset; respiratory activity follows dotted line A to K, when the experiment was terminated.

Set II.—Apples in air—solid line A to B; then in 10% carbon dioxide—dotted line B to C; again in air—solid line C to D; finally again in 10% carbon dioxide—dotted line D to E. At this point the experiment was discontinued.

Set III.—Apples in air—solid line A to F; then in 10% carbon dioxide— dotted line F to H; again in air—solid line H to J, when the experiment was terminated. Note peaks and troughs in curves following changes from carbon dioxide to air and from air to carbon dioxide respectively. These are probably due to carbon dioxide going into or coming out of solution, or to some form of reversible combination, in the tissues.

The variable factors, temperature and carbon dioxide, differ in their effect upon the apple. While the effect of low temperature is to slow down the climacteric rise, that of carbon dioxide is to postpone it. Both factors, however, behave alike in decreasing respiratory activity.

The practical outcome from the grower's point of view is that whereas ordinarily cold-stored apples soften and turn yellow, those kept in gas-storage remain firm and retain their green colour. The contrast in behaviour as regards softening and yellowing is due to the fact that in the cold-stored fruit the climacteric change is proceeding, though slowly, whereas in the gas-stored fruit it is suppressed or postponed indefinitely.

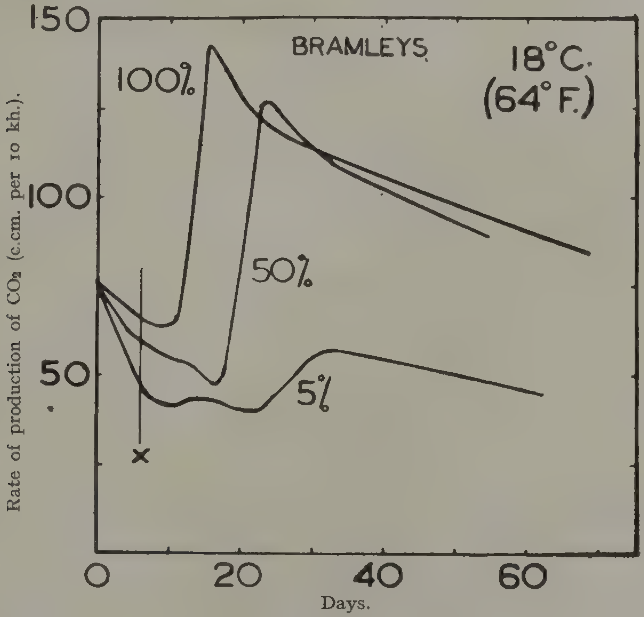

FIG. 6. Effect of Oxygen.

Apples transferred from air (21% oxygen) to atmospheres containing 5, 50 and 100% oxygen at the same point in time, marked X.

It is quite easy to cause damage to apples by subjecting them to too high a concentration of carbon dioxide. The limits of tolerance vary with the variety and with temperature. At higher temperatures the effect produced is that now well known as " brown heart " ; at lower temperatures the effects may closely resemble those of low-temperature injury and, in fact, the result may be regarded as low-temperature breakdown occurring sooner than it would have done in the absence of carbon dioxide. The reason for the wide variation in susceptibility of different varieties is not yet clearly understood. It is probable that some varieties have a much better system of internal aeration than others ; in consequence, in some varieties the internal atmosphere of the fruit at a given temperature may contain but little more carbon dioxide than the external atmosphere, in others it may contain considerably more. It should be borne in mind that it is the concentration of carbon dioxide in the atmosphere within the fruit that is effective.

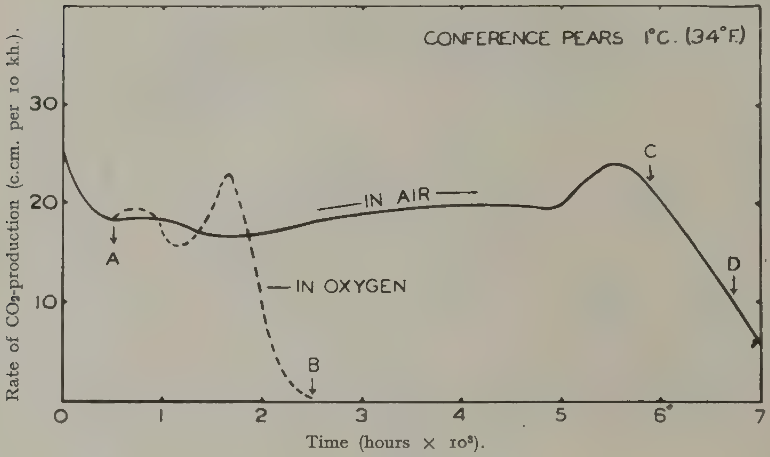

FIG. 7. Effect of Oxygen.

Two single pears gathered 29th September. The rate of carbon dioxide production of the one kept in air follows the course of the solid line. At C, the fruit showed no surface browning ; at D the skin was completely brown, as was also three-quarters of the flesh.

The other pear was exposed to pure oxygen from the point marked A onwards, and its rate of carbon dioxide production then followed the course of the dotted line. At B it was completely brown, both externally and internally.

THE EFFECT OF OXYGEN.

In the absence of oxygen, or in very low percentages of this gas, alcohol is produced and accumulates in the tissues to the detriment of the fruit. The concentration of oxygen below which the fruit forms alcohol rises progressively with the age of the fruit. In immature, half-grown apples, the concentration of oxygen can be reduced to less than one half per cent. without alcohol formation ; with fruit gathered at the normal time the limit is in the region of 2 per cent. ; whilst with fruits that are yellow and ripe, alcohol may be formed even in ordinary air (21 per cent. oxygen).

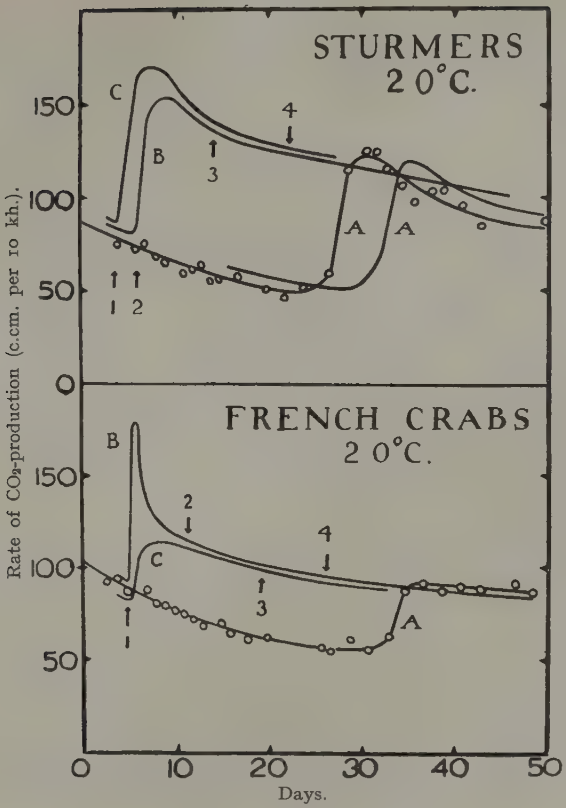

Fig. 8. Effect of Apple Vapour and Ethylene.

Sturmers. Four apples gathered 10th October, 1932.

Curve A. Untreated fruits in a slow current of fresh air.

Curve B. Air containing one part in 300 of ethylene substituted for pure air at time marked 2; climacteric rise immediately follows. Pure air re-substituted at time marked 3; no effect.

Curve C. At time marked 1, pure air substituted by air drawn through container holding 4 ripe apples, and then through strong caustic soda prior to passing over experimental apple; climacteric rise immediately follows. At time marked 4, pure air re-substituted; no effect.

French Crabs. Three fruits gathered 12th October, 1932.

Curve A. Untreated fruit as above.

Curve B. Ethylene (1 in 300) applied as above at time marked 1. Return to pure air at 2. Ethylene again applied at 4.

Curve C. Apple-vapour applied as above at time marked 1. Return to pure air at 3.

Note. Actual readings shown on two curves only, to indicate extent of smoothing employed in drawing figures.

Above the point on the oxygen scale at which alcohol is formed, the activity of the fruit, as measured by the production of carbon dioxide, increases slightly with the concentration of oxygen. In gas-storage, therefore, the lowest concentration of oxygen consistent with the non-production of alcohol in the fruit should be aimed at.

The concentration of oxygen also affects the trend of respiratory activity. In the absence of oxygen the climacteric does not occur, and its onset cannot be stimulated by the use of ethylene. In pure oxygen, the sequence of changes is telescoped into a much shorter period than that which obtains in air. Examples of the effects of different concentrations of oxygen are given in Figs. 6 and 7, for apples and pears respectively.

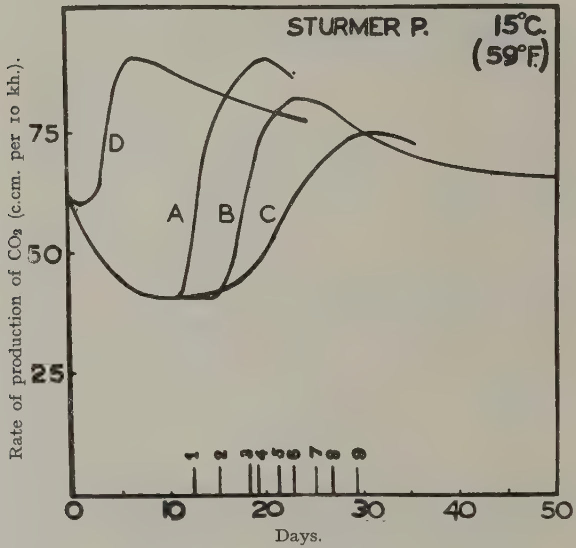

FIG. 9. The Group Effect.

A.—Rapid ventilation, 12 apples together in 1 jar.
B.—Slow ventilation, 12 apples together in 1 jar.
C.—Rapid ventilation, 9 apples, each isolated in its own separate container.
D.—Identical with lot A, but treated with vapour of ripe apples.
1—9. Time of onset of climacteric rise in each separate individual of Lot C.

A reduction in the concentration of oxygen when there is no carbon dioxide present has but little effect upon the fruit in storage, softening and yellowing, for example, being only slightly retarded (see Fig. 1).

This necessarily very brief sketch of the effect of the three factors, temperature, oxygen concentration and carbon dioxide concentration, is intended to emphasize the need for careful control of each of them in refrigerated gas-storage for fruit.

THE EFFECT OF VOLATILE SUBSTANCES.

In any form of gas-storage of fruit involving the use of gas-tight chambers, the problem of the effect of the accumulation in the storage atmosphere of volatile products other than carbon dioxide is encountered. At present only the harmful effects of their accumulation are known. For example, the injury known as "scald", which is attributed to the accumulation at the surface of the fruit of an unknown substance or group of substances, would have rendered gas-storage of apples quite impracticable unless suitable preventive measures had been available. Fortunately the practical method, devised in the U.S.A., of wrapping the apples in oiled paper, has proved just as effective in controlling "scald" in gas-storage as it has done in ordinary cold-storage.

One important recent discovery has been that during their climacteric phase apples, pears and certain other fruits produce small, but definite quantities of ethylene gas. This discovery resulted from an observation that apples had a marked inhibitory effect on the sprouting of potatoes and the germination of seeds, the effect being very similar to that of traces of ethylene in the atmosphere.

Ethylene stimulates the onset of the climacteric in apples and other fruits (Fig. 8). It will at once be realized that when ripe fruit is kept in the same chamber as unripe fruit there is a great risk of losing the advantage that would be gained by carbon dioxide in the atmosphere, because the ripe fruit may stimulate the climacteric in the unripe fruit (Fig. 9).

CONTROL OF THE ATMOSPHERE FOR OTHER FRUITS.

Turning, in conclusion, to the use of refrigerated gas-storage for other fruits, it has been shown for the banana that the effect of carbon dioxide and of oxygen on respiratory activity and on the onset of the climacteric is similar to that described above. The banana, when gathered for export, is a green pre-climacteric fruit. The yellowing of the skin begins after the climacteric. Gas-storage trials in England with the most retarded fruit available after overseas transport, have shown that the time taken to reach full ripeness, under gas-storage conditions, is approximately double that taken in air at the same temperature. There have been no experiments on the refrigerated gas-storage of bananas straight from the plantation.

Pears differ from apples and bananas in that the eating-ripe stage coincides with the peak of the climacteric, whereas with apples and bananas the fruit is not eating-ripe until some time after the peak of the climacteric has been passed. Refrigerated gas-storage is particularly effective with pears. This fruit is normally gathered a week or two before the climacteric. The onset of the climacteric with the concomitant softening and yellowing of the fruit appears to be prevented under the conditions of refrigerated gas-storage. On removal to air at higher conditioning temperatures, the fruit develops its climacteric and ripens normally.

The available data on the effect of oxygen and carbon dioxide on plums, peaches, grapes and citrus fruits are very meagre. On theoretical grounds, however, there seems to be no reason why the principle of atmospheric control should not be utilized in the storage of these fruits.

SUMMARY.

An account is given of the development of the refrigerated gas-storage method of keeping fruit, mainly apples and pears. The principles of the method are outlined and methods of construction of gas-tight chambers are given. Control of the composition of the air in the store is dealt with and the necessary instruments indicated. The advantages of gas-storage over ordinary cold-storage are set out and the behaviour of the fruit as influenced by temperature, oxygen and carbon dioxide concentration, and volatile substances is discussed. The probable suitability of the refrigerated gas-storage method for other types of fruit is pointed out.

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ON THE GROWTH AND CARBOHYDRATE SUPPLY OF THE TEA PLANT AFTER PRUNING

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INTRODUCTION.

The tea plant, owing to the economic value of its products, is now grown in many countries, the main centres of cultivation being China, Japan, India, Ceylon, Java and Sumatra. In some tea growing countries a "wintering" season is experienced, during which active growth ceases; but in Ceylon, Java, Sumatra and South India the climate is sufficiently equable to permit of continuous growth throughout the year. This paper discusses experiments carried out in Ceylon.

A central massif of Archaean gneissic rock is found in Ceylon rising in three peneplains. The first lies between one hundred and three hundred feet, the second between sixteen and nineteen hundred feet and the third at about six thousand feet above sea level. On these, and on the steeper slopes between them, the full range from that of a tropical climate in the lowlands to a montane sub-tropical climate at the highest elevations is experienced. Meteorological data for three stations on the three peneplains are as follows (1):—

Station.	*Elevation in feet.*	*Mean temperature °F.*	*Average percentage humidity.*	*Annual rainfall, inches.*	*Number of rainy days.*
Ratnapura ..	113	80·8	73	151·56	227
Kandy ..	1,611	76·7	71	84·11	191
Newara Eliya ..	6,170	59·5	75	93·38	206

No consistent difference is found save in temperature, in association with which a gradual change is noticeable from the rapid growth at the low elevations to the slow growth in the montane sub-tropical jungle (2).

The tea plant is an evergreen shrub grown solely for the sake of its leaves, the majority of which are steadily removed as fast as they are produced. The tea bush normally grows as a large shrub or small tree. Under cultivation in Ceylon, however, it is periodically pruned to produce a low, spreading bush with a flat top. The new shoots produced after pruning are allowed to grow unchecked until the stage of "semi-lignification" (3) begins at the base of the shoots. The bushes are then "tipped" by breaking back all shoots to a given height, normally about four and a half inches above the level of the pruned surface. This operation is afterwards repeated twice at short intervals, when those shoots that have not previously reached the "tipping" level are broken back. Soon after the completion of the third "tipping" operation, secondary shoots develop from those broken back at the first, and thereafter the bud and first two leaves of the shoots are harvested at regular intervals. One normal leaf is left above the scale leaves on the base of the shoot. From the axil of this leaf and those of the scale leaves other shoots are produced which are harvested when they reach a suitable size, i.e. when they have developed three normal expanded leaves. Where a shoot has developed more than three leaves between two plucking rounds, the extra leaf is discarded.

THE PROBLEMS.

The effects of climate and pruning on the growth of the tea bush in countries where growth is continuous throughout the year has not previously been adequately examined save for investigations upon the causes that result in the death of bushes after pruning. Bamber (4) showed that by allowing one branch per bush to remain unpruned, but plucking during the period of recovery from pruning, an enhanced yield ensued during the subsequent nine months. That experiment was carried out at Peradeniya at an elevation of 1,500 feet.

Petch (5) described a disease, colloquially known as the "Diplodia" disease of tea, normally noticeable only after pruning, in which either the bushes fail to recover or a larger or smaller number of branches die back, and he noted that in Ceylon it occurred mainly at the lower elevations. He ascribed the disease to the fungus *Botryodiplodia Theobromae* Pat., and recommended liming and the burning of dead bushes, together with the cessation of the practice of burying woody tissues in the soil. Small (6) concluded that the sudden death of tea bushes after pruning was due to infection by *Rhizoctonia bataticola* (Taub.) Butler. Gadd (7) pointed out that starch is normally found only in the roots of the tea bush, very little being found in the stem. He found that the roots of bushes that had died after pruning were destitute of starch, whereas it was present in the roots of healthy bushes and of those that had died as the result of infection by root disease fungi. He concluded that the occurrence of *Botryodiplodia Theobromae* on the roots of bushes that had died after pruning was secondary, the primary cause of death being lack of sufficient starch reserves in the roots to enable recovery when the bush was pruned. He (8) also contested Small's views on the association of *Rhizoctonia bataticola* with failure to recover after pruning.

The present paper reports an attempt to clarify and extend existing knowledge of the factors affecting the growth of the tea plant in Ceylon. In the course of this study the following five lines of investigation were undertaken: *Firstly,* the influence of three types of pruning upon the incidence of death of complete bushes and of individual branches after pruning, at low elevations; *secondly,* the influence of three types of pruning upon the number of primary shoots produced after pruning, both at a high and a low elevation; *thirdly,* the influence of three types of pruning upon the rate of growth of primary shoots at low elevations, and the relationship between the leaf area on the bush and the rate of production of secondary shoots; *fourthly,* the growth of the bushes subsequent to recovery from pruning at elevations of 4,600 feet, 1,500 feet and 200 feet above sea level, as influenced by three types of pruning; and *fifthly,* the reserves of the tea bush as influenced by type of pruning and climate.

THE METHODS.

The first pruning method employed was to cut all branches down to a height of eighteen inches above ground level, and to remove all thin stems and twigs, leaving only a variable number of thick frame-branches, with the result that the pruned bush was almost entirely leafless (Fig. 3). This method which, for convenience, will be described by the colloquial name of "clean" pruning, is susceptible of variation in two directions. In the first, more leaves may be left on the bush during the period of recovery from pruning if a number of branches are not pruned until a few days before the "tipping" operation, when convenience demands their removal at the same height as the other frame branches. The final result of such a method is that a greater leaf area is present during the period of recovery from pruning, while the final effects upon the frame are the same as those which result from "clean" pruning. This type of pruning will be referred to as "lung" pruning (Fig. 3).

The second line of possible variation lies in the removal of fewer branches below the pruning level. This results in the retention of more leaves on the bushes during the recovery period (after which the older leaves tend to fall off) than after "clean" pruning, but fewer than after "lung" pruning. The removal of fewer branches results in the presence of a considerably greater amount of shoot initials on the pruned bush, while the average age of the branches is reduced by the presence of the younger shoots that are removed during pruning by the two other methods. The extreme case, in which only diseased branches are removed below the pruning level, is denoted here by the term "cut across" pruning (Fig. 3).

These three types of pruning, namely "clean", "lung" and "cut across", were selected for trial at three elevations above sea level. Six average sized branches per bush were left unpruned until a few days before "tipping" in the "lung" pruned plots. The centres chosen for the sites of the experiments were Talawakelle (4,600 feet), Peradeniya (1,500 feet) and Kiriella (200 feet). The first lies between the second and third peneplains, while the two latter lie in the second and first respectively.

The differences between the climates in which the three sections of the field experiments were carried out are mainly those connected with increasing elevation, all three places being subject to rainfall during both monsoon periods. In the absence of meteorological stations at Peradeniya and Kiriella, data are given for Kandy and Ratnapura, the distances from Peradeniya to Kandy, and from Kiriella to Ratnapura being two and a half miles and seven and a half miles respectively. The climates of the two experimental centres are essentially similar to those of Kandy and Ratnapura respectively. At Talawakelle the meteorological data were collected about half a mile from the plots. Averages drawn from the records obtained during the course of the experiments are as follows:—

Climatic Data for the Three Centres.

	1932-33.			1933-34.		
	Talawakelle.	Kandy.	Ratnapura.	Talawakelle.	Kandy.	Ratnapura.
Mean temperature, ° F.	65·1	76·2	80·6	64·5	75·8	79·9
Annual rainfall, inches ..	92·81	90·11	151·79	132·40	112·69	190·62
Number of rainy days ..	254	211	268	261	217	273
Mean rain per rainy day	0·37	0·43	0·57	0·51	0·52	0·70

The mean temperature for any day is taken as the mean of the minimum at 09·30 hours and the maximum at 15·30 hours.

The most striking climatic change with increasing altitude is the reduction in temperature. In general, the mean temperature of the air bears a linear relationship to elevation. The linear regression calculated on data from eight meteorological stations in Ceylon, neglecting the seaboard stations immediately influenced by the proximity of the Indian Ocean, is $t=81·877-0·348x$ where t is the mean temperature in degrees Fahrenheit and x is the elevation in hundreds of feet. Diurnal variations in temperature show no steadily increasing trend with greater altitudes. The mean diurnal variations at Nuwara Eliya (6,170 feet), Talawakelle, Kandy and Ratnapura are 17·7° F., 14·6° F., 15·2° F. and 15·6° F. respectively.

The mean diurnal variation as a whole is reduced by greater cloudiness in the evening than in the morning, which also tends to raise the mean temperatures by reducing radiation at night.

The mean annual cloud amounts are:—

	09·30 *hours.*	15·30 *hours.*
Talawakelle	6·1	7·9
Kandy	5·8	7·1
Ratnapura	5·7	7·5

No records of the mean number of hours of bright sunshine are available for Ratnapura, but for Kandy and Talawakelle the values are 5·5 hours and 5·1 hours respectively. In general, the higher the elevation the less the number of hours of bright sunshine.

No general trend is noticeable in the annual rainfall ; it depends to a great extent on the local configuration of the district. The centres under discussion all receive over ninety inches of rain per annum, and under natural conditions support evergreen rain forest, save where edaphic factors lead to the formation of " patna " grassland. The number of rainy days in the year is large, and they are well distributed. The amount of rainfall per rainy day tends to decrease at high elevations, the rain frequently falling in the form of a fine drizzle, especially during the south-west monsoon.

The three pruning treatments previously described were compared by field arrangement as " randomized blocks ". At Peradeniya and at Kiriella the blocks, six in number, consisted of three plots each ; each block included the three treatments, their positions within the block being assigned at random. At Talawakelle the plots were randomized in six blocks of nine plots each, and comprised one third of a larger experiment in which the effects of the season of pruning were being examined in addition to those due to differences in type of pruning.

The size of the plots was based upon the finding of Eden (9) that, with a given experimental area, plots of between 1/18th and 1/8th of an acre are most effective, the enhanced accuracy to be expected from larger plots being lost by the reduced replication involved. It is necessary that each plot should contain whole numbers of bushes, accordingly each was arranged to consist of two hundred and fifty bushes on about 1/12th of an acre.

In 1933 an additional experiment upon the relation between the number of leaves left on the pruned bush and recovery from pruning was carried out at Kiriella. Three methods of pruning were compared, namely " clean " pruning, and two types of " lung " pruning, in which either three or six branches per bush were left unpruned. The three treatments were imposed on eight randomizd blocks, in each of which each treatment occurred once. Each plot consisted of two hundred bushes and was divided into two subplots of one hundred bushes each, to which were assigned at random either " early " or " late " removal of the " lungs ".

The pruning of one block was completed before that of another was begun, so that differences due to the unavoidably long periods taken to complete the pruning, fall into the block variance. Counts of the number of leaves on ten bushes, taken at random in each subplot, were then made, the blocks being taken in the same order as that in which they were pruned, each block being dealt with approximately nineteen days after pruning. The weight of tippings per subplot was recorded and two collections were made of Die-back, the first soon after "tipping" and the second eighty days after. The period between pruning and the first collection was approximately equal to that elapsing between the first and second collections. At each collection the number of dead bushes was recorded.

Records were taken in all the field experiments of the weight of material removed in the "tipping" operations, while the weight of shoots harvested on each plot after recovery from prunning was recorded in the 1932 experiments. The fresh weight yields were measured near the plots, and two samples of 50 gm. wet weight of "tippings" and two samples of 25 gm. of flush* were drawn from the material collected from each plot. The samples were taken from the field and dried at approximately 95° C. From them the percentage of dry matter in the material from each plot was determined and used in the calculation of its yield. This method (9) had been found necessary owing to the uneven incidence of superficial moisture during the day.

At Kiriella and Talawakelle counts were made on all occasions of the number of complete shoots present in each 25 gm. sample of flush, fragments used in making up the exact weight being neglected. In this way a constant check was kept upon the standard of plucking, while it enabled estimates to be made of the number of shoots dealt with on each plot.

The leaf areas on the pruned bushes in the experiments at Kiriella were estimated by counting the number of leaves on bushes taken at random, this being the only feasible method owing to the large size of the experiments.

The calendar of operations performed in connection with these two series of experiments was as follows:—

1932 *Experiments* (*Three Centres*).

Dates of operations.

Place.	*Pruning.*	*"Clean" pruned plots.*		*"Lung" pruned plots.*		*"Cut Across" plots.*	
		1st "Tipping".	*1st Harvesting.*	*1st "Tipping".*	*1st Harvesting.*	*1st "Tipping".*	*1st Harvesting.*
Talawakelle ...	May 10th-13th	Sept. 2nd	Oct. 22nd	Aug. 24th	Oct. 22nd	Aug. 24th	Oct. 22nd
Peradeniya ...	May 6th-7th	July 21st	Aug. 30th	July 20th	Aug. 30th	July 9th	Aug. 23rd
Kiriella ...	April 28th-30th	July 14th	Aug. 24th	July 7th	Aug. 17th	June 24th	Aug. 3rd

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* A technical term denoting the portion of the young shoots harvested for manufacture into tea.

1933 *Experiment* (*Kiriella only*).

Dates of operations—Kiriella.

	Date.
Pruning	May 11th-23rd
Lung removal:	
"Early"	June 20th
"Late"	July 20th
Leaf counts	May 29th-June 15th
"Tipping"	August 4th
First collection of dead wood	August 10th-11th
Collection of root samples	August 10th-11th
Second collection of dead wood	October 31st

It was noted in 1932 that the effects of pruning varied in character at the different centres. At Talawakelle, the branches remaining on the bush after pruning produced new shoots along their length in a normal manner, except that occasionally shoot production was delayed. The only instance in which branches died back occurred when the pruning cut had been made some distance above a bud, when it died back as far as the eye. At Peradeniya, a slight tendency for a few branches to die back beyond a healthy bud was observable. At Kiriella, however, large numbers of branches were observed to die during the period elapsing between pruning and "tipping", while in each plot a number of bushes failed to recover at all. Counts were therefore made of the number of dead bushes at the "tipping" stage, while the amount of Die-back of frame branches was estimated by carefully removing all dead branches and recording the total weight collected from each plot.

Records were taken during the course of the experiment begun in 1933 of the number of dead bushes, the amount of Die-back, and the weight of shoots and leaves removed in the "tipping" operation.

The value of "tipping" yields as an index to the new growth after pruning was examined at Kiriella. Two hundred bushes were "clean" pruned and the fresh weight of "tippings" and the total fresh weight of new shoots produced recorded for each individual bush. The correlation between the two characters was found to be $r = +0{\cdot}831$; the weight of "tippings" thus provides a fairly satisfactory measure of the weight of new shoot growth.

The reserve materials of the tea bush were investigated by analysis of root samples, total carbohydrates and total nitrogen content being determined. Gadd's evidence (7) that the amount of starch reserves in the root played an important part in causing the Diplodia disease suggested that carbohydrate reserves were at a minimum in those bushes which either died or made only a poor recovery after pruning. It is possible, however, that compounds more complex than starch may be used by the bush, although starch appears to be the main reserve carbohydrate. Murneek (11) and Tottingham *et al* (12), among others, have shown that hemicelluloses may act as reserve substances.

As oven-drying of the samples rendered the separate estimation of soluble sugars, starch, etc., of doubtful value, it was decided to estimate total carbohydrates. This was done firstly in roots from tea grown at varying elevations above sea level, and secondly in roots derived from the 1933 pruning experiment at Kiriella. The former experiment was undertaken to discover the reason for the variation in reaction to pruning at different elevations, and the latter to determine the effect of different methods of pruning upon the carbohydrate level of the bush.

The size of the roots collected was standardized at half-an-inch diameter when fresh. The samples were oven-dried at 95° C. and after splitting into fragments, were ground in a coffee mill to pass a forty mesh sieve. Before analysis the material was dried for five hours at 95° C. The method adopted consisted of the hydrolysis of 2·5 to 3·0 gm. of the dried ground material with 220 c.cm. of 2·25 per cent. hydrochloric acid (13). The flasks, fitted with reflux condensers, were plunged into a vigorously boiling water bath and heated for exactly two and a half hours.

The dark red extract obtained was filtered hot into a flask containing a slight excess of solid lead carbonate, and the residue washed with distilled water until the washings were colourless. The filtrate was cooled by immersion in water, followed by the addition of about 50 gm. of ice from distilled water. The solid matter was filtered off, and the solution freed from lead salts with 10 per cent. sodium carbonate solution and made up to 500 c.cm.

In the series of analyses of root samples from tea grown at different elevations the method was modified to avoid the tedious washing of the basic lead carbonate precipitated during de-leading. The solution was made up to 500 c.cm., the requisite amount of sodium carbonate added and the whole made up to 550 c.cm. The precipitate was allowed to settle and the volume required for analysis decanted off and filtered.

Reducing substances were estimated by Lane and Eynon's modification (14) of Fehling's method, involving the use of methylene blue as an indicator. The concentration of reducing substances in the extract was too low to allow of accurate estimation directly by this method, and for analysis the extract was mixed with an equal volume of standard 1 per cent. glucose solution. The glucose equivalent of the reducing substances present was expressed as a percentage of the total dry weight.

THE DEATH OF BUSHES AND THE DIE-BACK OF BRANCHES AFTER PRUNIING.

The variation in recovery after pruning which is associated with elevation above sea level rendered it unnecessary to examine the subject in detail at Talawakelle or Peradeniya and investigations were confined to Kiriella. The mean number of dead bushes per plot recorded after the completion of the "tipping" in the 1932 experiment at Kiriella is shown below, together with the calculated values of z (10)*.

Method of pruning	*"Lung"*	*"Clean"*	*"Cut Across"*
Number of deaths	1·3	11·2	4·5

Mean square due to		Mean square due to	Degrees of freedom	z calculated	z P=·05	z P=·01
Treatment	v	Treatment × Block	2v10	1·3301	0·7058	1·0114
Block	v	Treatment × Block	5v10	0·2073	0·6009	0·8646

Analysis of the data indicates that the number of deaths was influenced by the pruning method, but not by position within the field. The significant difference† between treatments is 4·2 and thus both "lung" and "cut across" pruning resulted in fewer deaths than did "clean" pruning.

All stages were observed from bushes in which very little Die-back occurred after pruning to bushes which died completely. A measure of the average status in this respect of the bushes within a plot is given by the weights of dead branches; these are shown below, together with the calculated values of z.

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* Complete "analyses of variance" (10) are not presented, only the essential data referring to the comparisons under discussion being given.

† $t_n = \sqrt{2S} \div \sqrt{N}$ where t_n is the value of t for P=·05 when n degrees of freedom are available for the estimation of error, and where S is the mean square deviation and N the number of plots.

Method of pruning	*"Lung"*	*"Clean"*	*"Cut Across"*
Weight of Die-back	21·7 lbs.	57·7 lbs.	37·8 lbs.

Mean square due to		Mean square due to	Degrees of freedom	z calculated	z P = ·05	z P = ·01
Treatment	v	Treatment × Block	2v10	1·6188	0·7058	1·0114
Block	v	Treatment × Block	5v10	1·0931	0·6009	0·8646

The value of z for treatment indicates that pruning treatment significantly affected the amount of Die-back. Since the significant difference between treatments amounted to 11·3 pounds, it follows that "cut across" and "lung" pruning resulted in less Die-back than "clean" pruning. It is noteworthy that the block variance is also significantly greater than the estimate of the experimental error, indicating that the amount of Die-back was affected by position within the field. There is evidence that this is associated with differences in the number of leaves left on the bushes in the different blocks. The number of leaves on forty bushes in each plot was counted between May 28th and June 1st, 1932, i.e. one month after pruning, before new growth had occurred. The mean numbers of leaves per bush were found to be:—

"Lung"	*"Clean"*	*"Cut Across"*
226·2	9·5	61·3

In addition to the wide differences between the treatments, there were also differences between blocks. The following coefficients of correlation between leaf number and weight of dead wood were found by an analysis of covariance:—

		r P = ·05
Total	$r = -0{\cdot}72$	0·46
Treatment	$r = -0{\cdot}94$	0·95
Blocks	$r = -0{\cdot}88$	0·75
Error	$r = +0{\cdot}29$	0·58

Although there is distinct evidence of a general relationship between Die-back and leaf number, the treatment value is just not significant. This is almost certainly due to the facts that there are only two degrees of freedom available for its estimation and that the three systems of pruning do not fall into a graded series. But it appears that a large part of the block variance in the Die-back experiment is associated with variations in the number of leaves left on the bush after pruning in different blocks. Visual observations on the plots suggested that these differences were due to variation in the size of bushes, resulting in differences in the number of leaves per bush that remained after the pruning operation. The value for error is quite insignificant and no useful purpose is therefore served by correcting the Die-back data for variations in leaf number by means of a regression (16).

The general connection noticeable between the number of plants dying after pruning and the amount of Die-back gives support to the impression gained from field observation that the causes of Die-back and of the death of complete bushes after pruning are of similar nature, while the connection between the intensity of their incidence and the number of leaves on the pruned bushes supports Gadd's (7) hypothesis concerning the cause of the Diplodia disease.

The data discussed were obtained from bushes that had been steadily plucked up to the time of pruning, and it is possible that this had affected the results. The constant removal of the young shoots by plucking must result in reducing the amount of carbohydrates available for deposit as reserve, owing to the constant stimulus to the production of new growth which is removed before it can have taken sufficient part in photosynthesis to compensate for the carbohydrates used in its production. The mean dry weight of one plucked shoot at Galatura was 0·1232 gm. (22). Using the interval between the first "tipping" and the first harvest, i.e. thirty-nine days, as an estimate of the time taken to develop, it follows that the shoot increases in weight at a mean rate of 51 mg. per gm. per day, the corresponding value at Talawakelle being 40 mg. This is much higher than that observed by the author in complete young tea plants, where the highest rate observed was 19 mg. per gm. per day when twenty-eight weeks old. The corresponding value for the stem and leaves only was 17 mg. per gm. per day. It is probable, therefore, that the shoot manufactures not more than half of the carbohydrates necessary for its growth.

If Die-back is associated with carbohydrate deficiency, the production and removal of large numbers of flush just before pruning should thus cause more Die-back. In order to test this conclusion thirty bushes were pruned after their yields had been recorded weekly for eight months and the Die-back per bush was weighed. A correlation of $r = -0{\cdot}04$ was found between weight of Die-back and total yield per bush during the period. This value does not differ significantly from zero, and thus there was no association between the amount of Die-back and yield over a period of eight months. A significant positive correlation of $r = +0{\cdot}35$ was, however, found between the yield of the bushes at the last four pluckings before pruning and the amount of Die-back. Thus, the production of a larger number of shoots during the month before pruning increased the amount of Die-back. The value of the correlation coefficient is, however, so low that it can be regarded only as indicative.

A further experiment was started at Kiriella in May 1932, the design of which has already been described. The tea subjected to experiment had not been plucked for five months previous to pruning, and during this time it was allowed to grow unchecked. Comparison of bushes in which six, three, or no branches were left unpruned enabled further investigation of the relation between the number of leaves on the pruned bush and Die-back to be made.

The mean number of leaves per bush nineteen days after pruning is shown below for each of the five treatments, together with the values of *z* calculated from the data.

Number of unpruned branches	0	3		6	
Time of removal	—	Early	Late	Early	Late
Number of leaves	3	207	198	318	338

Mean square due to		Mean square due to	Degrees of freedom	*z* calculated	*z* P = ·05	*z* P = ·01
Treatment	v	Treatment × Block	2v14	3·1593	0·6594	0·9370
Blocks	v	Treatment × Block	7v14	0·5519	0·5098	0·6408
Time of removal	v	"Lung" Number × Time of removal	1v1	0·9225	2·5421	4·1535
"Lung" Number × Time of removal	v	Remainder	1v22	0·5769	0·7294	1·0363

The treatments differ significantly in the number of leaves left upon the bush, but the difference between the early and late sub-plots is not significant. There is again a difference in the number of leaves left on the bushes in different blocks, but it is only just significant. It may be accepted, therefore, that the bushes differed in respect of number of leaves only according to the pruning treatment and the block in which they were situated.

As before, "lung" pruning was found to result in a considerable reduction in the number of deaths occurring after pruning. The mean numbers of deaths per sub-plot of one hundred bushes that occurred between pruning and the first collection of dead wood, and between the first and second collections, are shown below. A complete analysis of the distribution of deaths after pruning is prevented by the fact that a class occurs in which no deaths took place. The results of analysis of the total deaths are therefore given.

Number of unpruned branches	0	3		6	
Time of removal	—	Early	Late	Early	Late
First period	4·81	0·75	0·75	0·25	0·75
Second period	0·81	0·28	0·00	0·25	0·25
Total	5·62	1·03	0·75	0·50	1·00

Mean square due to		Mean square due to	Degrees of freedom	z calculated	z P = ·05	z P = ·01
Treatment	v	Treatment × Block	2v14	1·6627	0·6594	0·9370
Blocks	v	Treatment × Block	7v14	0·2065	0·5098	0·6408
Time of removal	v	"Lung" Number × Time of removal	1v1	0·0785	2·5421	4·1535
"Lung" Number × Time of removal	v	Remainder	1v22	0·1242	0·7294	1·0363

While the pruning treatment again influenced the numbers of deaths, the time at which the unpruned branches were removed had no influence, and there is no evidence of any interaction between the time of their removal and their number.

Analysis of the data shown below for *whole* plots during the first and second periods gives significant values of z for treatment of 1·6193 and 1·7210 respectively.

Number of unpruned branches ..	0	3	6
Deaths in first period	9·62	1·50	1·00
Deaths in second period	1·62	0·28	0·50

The significant difference between treatments derived from the data is 2·63 for the first collection and 0·80 for the second. Thus, during both periods the number of deaths was influenced only by the presence or absence of unpruned branches, there being no significant difference between the plots in which three and those in which six branches were left unpruned.

The similarity between the occurrence of deaths and of Die-back before "tipping", noted in the 1932 experiment, was again observable in this experiment. The mean weights of dead wood removed (in pounds per sub-plot) during the first and second collections were:—

Number of unpruned branches	0	3		6	
Time of removal	—	Early	Late	Early	Late
First collection	23·7	15·0	10·5	11·8	10·1
Second collection	5·1	4·8	3·9	4·8	5·1
Total	28·8	19·8	14·4	16·6	15·2

The results of the statistical analysis of the data are shown below:—

First collection.

Mean square due to		Mean square due to	Degrees of freedom	z calculated	z P = ·05	z P = ·01
Treatment	v	Treatment × Block	2v14	1·3613	0·6594	0·9370
Blocks	v	Treatment × Block	7v14	0·0624	0·5098	0·6408
Time of removal	v	"Lung" Number × Time of removal	1v1	0·8350	2·5421	4·1535
"Lung" Number × Time of removal	v	Remainder	1v22	0·1512	2·7571	4·3672

Second collection.

Mean square due to		Mean square due to	Degrees of freedom	z calculated	z P = ·05	z P = ·01
Treatment	v	Treatment × Block	2v14	0·2495	1·4832	2·2997
Blocks	v	Treatment × Block	7v14	0·7019	0·5098	0·6408
Time of removal	v	"Lung" Number × Time of removal	1v1	0·8596	2·5421	4·1535
"Lung" Number × Time of removal	v	Remainder	1v22	0·0571	2·7571	4·3672

The effects of the different methods of pruning on the amount of Die-back varied significantly in the first period. The significant difference between the treatment values is 5·4 pounds ; thus, while "clean" pruning resulted in more Die-back than did either form of "lung" pruning, differences in the number of unpruned branches had no effect. In the second period, no differences occurred between the effects of the pruning treatments. This indicates that while the presence of unpruned branches resulted in less Die-back during the first period, no continued benefit remained after their removal. This was not found to hold good when the number of deaths was considered.

The positional variance, while insignificant in the first set of data, is significant in the second. In neither period did the time of removal of the unpruned branches have any effect upon the amount of Die-back, nor was there any evidence of interaction between their number and the time of their removal.

THE NUMBER OF PRIMARY SHOOTS PRODUCED AFTER PRUNING.

The records collected at Talawakelle and Kiriella of the number of shoots in each dry-matter sample of 50 gm. of "tippings" allowed of the estimation of the total number of primary shoots produced in each plot after pruning.

The numbers, estimated from the fresh weight yield and the number of shoots in a sample of 50 gm. fresh weight, were:—

	"Lung"	*"Clean"*	*"Cut Across"*
Talawakelle ..	14,081	12,008	23,998
Kiriella	11,076	9,684	10,491

Mean square due to		Mean square due to	Degrees of freedom	z calculated	z P=·05	z P=·01
Treatment	v	Treatment × Elevation	2v2	0·0544	1·4722	2·2976
Elevation	v	Treatment × Elevation	1v2	0·2044	1·4592	2·2950
Treatment × Elevation	v	Remainder	2v20	1·9944	0·6254	0·8831

The values of z shown above indicate that neither the effects of elevation nor of pruning were significant when compared with the interaction between the two factors. The latter is very highly significant, showing that the district in which the experiment was performed influences the relative reactions to the different types of pruning. When the records of the two centres are examined individually, the value of z for treatment at Talawakelle is found to be 2·1227, the value of z for P=·05 and P=·01 being 0·7058 and 1·0114. Thus, the number of shoots produced after pruning was significantly affected by the method employed. The significant difference is 7644 and it follows that "cut across" pruning resulted in the production of significantly more primary shoots than did "clean" or "lung" pruning.

At Kiriella the value of z for treatment is only 0·6265 and the type of pruning employed cannot be said to have influenced the number of primary shoots produced.

The average weight per unit length of the branches remaining on "cut across" bushes is considerably smaller than that on "clean" or "lung" pruned bushes, owing to the removal of all the small shoots in the last two. The number of buds removed from participation in the production of new shoots by the occurrence of a given weight of Die-back is therefore greater on the "cut across" bushes, and a possible explanation of the observed differences in the numbers of primary shoots produced after pruning in the three ways at

Talawakelle and at Kiriella is that the difference between the number of buds on "cut across" bushes and on "clean" pruned bushes was greatly reduced at Kiriella by the incidence of Die-back at this elevation.

THE GROWTH OF PRIMARY SHOOTS AT A LOW ELEVATION.

As already stated, a fairly high correlation is found between the weight of "tippings" and the total weight of new shoots and leaves, and the weights of the former may therefore be used as a guide to the amounts of new growth produced after pruning. The mean dry weights in pounds per sub-plot of "tippings" removed in the 1933 experiment at Kiriella were:—

Number of unpruned branches	0	3		6	
Time of removal	—	Early	Late	Early	Late
Weight of "tippings" ..	2·19	3·29	3·84	4·84	4·39

Mean square due to		Mean square due to	Degrees of freedom	z calculated	z P=·05	z P=·01
Treatment	v	Treatment × Block	2v14	1·6535	0·6594	0·9370
Blocks	v	Treatment × Block	7v14	1·2705	0·5098	0·6408
Time of removal	v	"Lung" Number × Time of removal	1v1	1·1176	2·5421	4·3672
"Lung" Number × Time of removal	v	Remainder	1v22	0·9950	0·7294	1·0363

The values of z shown above indicate that the effect of varying the number of unpruned branches was significant. The greater the number of branches left unpruned the greater the weight of "tippings" produced, the differences between the mean values for the three pruning treatments being all greater than 0·71 pounds, the value of the significant difference. The block variance is strongly significant, but the data show no correlation between variations in the number of leaves on the bushes in different blocks and variations in the weight of "tippings", and it is probable that the block variance is mainly a measure of fertility differences. The differences in leaf area arising in this way between the blocks may possibly account for the occurrence of a significant positional variance in the number of deaths during the second period, when none was found during the period immediately following pruning.

The length of time for which the unpruned branches remained on the bush, again had no effect as a whole; but it is interesting that the interaction between the number of unpruned branches and the length of time they are present is significant, the greatest weight of "tippings" being produced by late removal when three were present and by early removal when six were present.

The fact that the yield of "tippings" when six branches were left unpruned for the longer period is less than when they were removed earlier suggests that they may exercise an inhibitory effect upon the production of new growth, which is masked so long as a carbohydrate deficiency exists.

Further data upon the relation between leaf area and the production of new growth after pruning were obtained during 1933, dry weight being used as a convenient measure of area. The mean dry weight of the flush, harvested from nine groups of twenty "clean" pruned bushes, was recorded during nine periods of sixty-three days after "tipping", the latter operation being completed one hundred and twenty days after pruning. At the end of each period, all the leaves were stripped from the group under observation, dried and weighed.

The weights (in gm.) were:—

Period.	*Flush.*	*Leaves.*
1	15·60	88·45
2	24·04	164·20
3	29·93	229·06
4	30·11	202·75
5	34·54	260·36
6	36·43	342·46
7	36·84	400·52
8	28·95	389·18
9	37·57	444·97

Examination of the data shows that while there was close agreement between the variations in leaf weight and flush weight in the first five periods, the last four show little trace of this. The values of the correlation coefficient over the two groups of periods are $r = +0{\cdot}99$ and $r = +0{\cdot}10$ respectively, the latter value being quite insignificant. The connection between leaf weight and weight of new shoots during the first five periods, suggests that the carbohydrate supply was a limiting factor in the production of new growth for about four hundred and thirty-five days after pruning. If this be so, the laying down of reserves could occur only after this.

The rate of leaf growth may play a part in influencing recovery from pruning when the amount of carbohydrate available is low. The rapid production of new leaves after pruning would reduce the period during which respiration is maintained on reserves alone and hasten the attainment of a positive carbohydrate balance. An experiment at Talawakelle in 1934 showed that the mean dry weights of leaves per bush (in gm.) at different periods after pruning were as follows:—

Days after Pruning.	*"Lung".*	*"Clean".*	*"Cut Across".*
0	55·7	0·9	25·0
27	56·1	0·9	32·1
54	63·6	2·5	38·6
81	124·6	25·9	102·4
108	180·8	64·8	162·2

The dry weight of the leaves on the "cut across" bushes rose much more rapidly than that of those on the bushes "clean" pruned, and quickly approximated to that on the "lung" pruned bushes. This is partly due to the more rapid growth of the buds on the younger branches left on the bush by "cut across" pruning, and partly to the greater number of young shoots produced. In view of these results, although the "cut across" plots in 1932 at Kiriella showed only 51·8 more leaves per bush than the "clean" pruned plots, it appears probable that this difference increased, the number of leaves on the "cut across" plots tending to approximate more to that on the "lung" pruned plots as recovery proceeded.

GROWTH SUBSEQUENT TO RECOVERY FROM PRUNING.

The crops harvested from the experimental plots during the two years subsequent to pruning provide a means of determining the length of time during which the differences seen to occur in the recovery period subsequently persist. While the relation between the weight of crop harvested under artificial treatment and the growth that would have been made had the bushes grown freely is at present obscure, because the flush is on the whole a constant fraction of the new shoot; yet the yield provides a measure of a portion of the new growth made under a uniform system of mutilation, which is, in effect, a form of "green wood pruning" in which the severity of the pruning is directly proportional to the new growth made.

The yields of the plots were recorded over a period of two years from pruning and the results are given below as total yields in pounds of dry matter per plot in the first and second years respectively.

	First Year			*Second Year.*		
	"Lung"	*"Clean"*	*"Cut Across"*	*"Lung"*	*"Clean"*	*"Cut Across"*
Talawakelle ..	44·66	48·56	46·62	68·20	74·53	63·46
Peradeniya ..	76·07	72·74	75·31	91·52	90·45	81·91
Kiriella ..	56·92	48·01	63·40	117·90	107·76	120·15
Mean ..	59·22	56·44	61·78	92·54	90·91	88·51

	Variance due to	Variance due to	Degrees of freedom.	*z* calculated.	*z* P = ·05	*z* P = ·01
A.	Treatment	v Treatment × District	2v4	1·1003	1·4787	2·2988
B.	Treatment	v Treatment × Year	2v2	0·6495	1·4722	2·2976
C.	District	v Treatment × District	2v4	1·5283	0·9690	1·4452
D.	District	v District × Year	2v2	0·2371	1·4722	2·2976
E.	Year	v Treatment × Year	1v2	2·5690	1·4592	2·2950
F.	Year	v District × Year	1v2	0·8269	1·4592	2·2950
G.	Treatment × Year	v Treatment × Year × District	2v4	1·2624	0·9690	1·4452
H.	Treatment × District	v Treatment × Year × District	4v4	1·7133	0·9272	1·3856
I.	Year × District	v Treatment × Year × District	2v4	3·0044	0·9690	1·4452

Considering the first order interactions shown above, the calculated values of *z* indicate that the relative responses to the three types of pruning varied according to the district (H) and in the first and second years (G). The differences between the yields of the experimental areas in the first year vary significantly from those in the second year (I), showing that the trend of yield with time varied according to the district.

The fact that all the first-order interactions have proved to be significantly greater than those of the second-order against which they were compared indicates that it is useless to draw conclusions from the yield totals for either treatment or for district or year. It is therefore necessary to consider the results of the experiment in each district in each year separately.

The values for z calculated from the data for each year at Talawakelle, Peradeniya and Kiriella are shown below, together with the significance differences in pounds.

	Talawakelle.	*Peradeniya.*	*Kiriella.*
z 1st year ..	0·7704	0·2513	1·9786
S.D. 1st year ..	2·85	—	3·67
z 2nd year ..	0·8640	0·4585	1·2847
S.D. 2nd year ..	6·30	—	5·75

z P·05 = 0·7058 and z P·01 = 1·0114

These values lead to the following conclusions, taking the yield of the "clean" pruned plots as the control:—

First Year.

Talawakelle ..	"Cut Across" = "Clean" > "Lung"
Peradeniya ..	"Cut Across" = "Clean" = "Lung"
Kiriella	"Cut Across" > "Clean" < "Lung"

Second Year.

Talawakelle ..	"Cut Across" < "Clean" > "Lung"
Peradeniya ..	"Cut Across" = "Clean" = "Lung"
Kiriella	"Cut Across" > "Clean" < "Lung"

The effects of "lung" pruning when compared with "clean" pruning were similar in the two years of the experiment, but varied considerably at the different stations. While at Peradeniya no difference was found, "lung" pruning caused a decrease in yield at Talawakelle and a marked increase at Kiriella. The magnitude of the differences varied little from year to year at the three stations and did not increase proportionately to the great yields produced in the second year; a result which suggests that the effects of the presence of leaves on the pruned bush diminish after a time. It has already been shown that yield becomes independent of the leaf area on the bush about fourteen and a half months after pruning.

"Cut across" pruning did not show any difference in yield from "clean" during the first year pruning at either Talawakelle or Peradeniya, but a significant increase occurred at Kiriella. In the second year the results were similar save that the "clean" pruned plots yielded significantly more than the "cut across " plots at Talawakelle. On comparison of the mean yields during the first and second years, it is apparent that the significance of the treatment × year interaction is mainly due to the lower yields of the " cut across " plots in the second year.

Although, in general, the yield in the second year was greater than in the first, the increase was not similar in different districts, as is evidenced by the significance of the year × district interaction. The greatest difference was at Kiriella, where the yield in the second year was more than twice as large as in the first, the relatively small yield in the first year probably being due to the Die-back of frame branches and the small number of primary shoots produced after pruning.

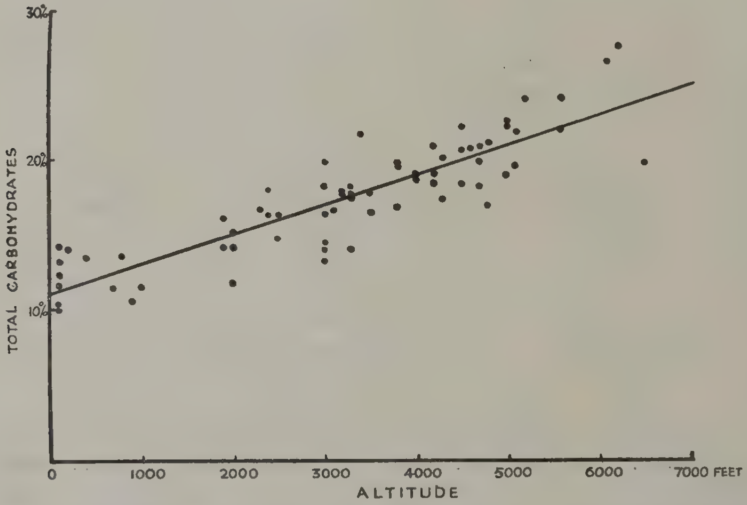

Fig. 1. The Percentage of Total Carbohydrates, expressed as Glucose, plotted against Elevation above Sea-level.

THE CARBOHYDRATE AND NITROGEN CONTENT OF THE ROOTS.

The marked differences between the effects of " lung " pruning at the three experimental centres, together with the observation that the Diplodia disease was observable only at low elevations, suggested a survey of the carbohydrate reserves in the roots of the tea bush at different elevations. Fields of tea that had been pruned sixteen to twenty months previously were selected, the majority having been pruned eighteen months earlier. Root samples were collected from sixty-nine fields, ranging in elevation from 100 feet to 6,500 feet above sea level. It was found that the percentage of " total carbohydrates ", expressed as glucose, when plotted against deviation gave distinct evidence of relationship between the two, the higher the elevation the greater the percentage of " total carbohydrates " (Fig. 1).

The linear regression calculated from the data is

$$y = 11{\cdot}17 + 0{\cdot}20x$$

where x is the elevation above sea level in hundreds of feet and y the percentage of " total carbohydrates " expressed as glucose.

It is desirable to determine firstly whether the coefficient of x differs significantly from zero, and secondly how closely this expression, which is the best fitting straight line, fits the facts, i.e. to what extent do the actual observations deviate from the linear relationship ? The standard error of the coefficient b is 0·013 and the value of t is 14·9858, indicating that the coefficient differs significantly from zero. The sum of squares of the deviation of y from its mean is 1013·98, whereas the sum of squares of the deviation of y from the regression is only 233·00. The regression thus accounts for 77 per cent. of the variance, a large proportion of the remainder doubtless being due to differences in the previous history of the fields from which the samples were drawn.

If the incidence of the Diplodia disease is accepted as being governed by the supply of carbohydrates during the period of recovery from pruning, the existence of this marked relationship between the carbohydrate reserves of the bush and elevation provides an explanation of the occurrence of the disease at low elevations only.

The difference in carbohydrate level at high and low elevations does not appear to be confined to plucked and pruned tea, for iodine tests on young seedlings have shown the presence of less starch at low than at high elevations.

Evidence that the presence of leaves on the pruned bush affected the carbohydrate balance during recovery was found when determinations were made of the " total carbohydrates " in root samples derived from the plots of the 1933 field experiment. The samples were taken when the plots were " tipped ", and consisted of a portion of root four inches long and half-an-inch in thickness from each of ten bushes selected at random in each sub-plot.

The mean percentage of " total carbohydrates " expressed as glucose were :—

Number of unpruned branches	0	3		6	
Time of removal	—	Early	Late	Early	Late
Percentage	10·62	13·39	13·41	13·42	12·90
Mean	10·62	13·40		13·16	

Mean square due to		Mean square due to	Degrees of freedom	*z* calculated	*z* P = ·05	*z* P = ·01
Treatment	v	Treatment × Block interaction	2v14	1·3977	0·6594	0·9370
Blocks	v	Treatment × Block interaction	7v14	1·3821	0·5098	0·6408
Time of removal	v	"Lung" Number × Time of removal	1v1	0·0775	2·5421	4·1535
"Lung" Number × Time of removal	v	Remainder	1v22	0·9893	2·7571	4·3672

Analysis indicates that the only significant variance, apart from that due to position effects, is that due to the number of unpruned branches. The significant difference between treatments is 2·32 per cent., thus the mean content of "total carbohydrates" in the roots at the "tipping" stage was increased by both forms of "lung" pruning, in spite of the large increases in the amount of new growth produced.

The analysis of co-variance between the number of leaves on the bush nineteen days after pruning and the percentage of "total carbohydrates", using the data for whole plots, gives the following values of *r*.

	Degrees of freedom	*r* *calculated*	*r* P = ·05
Total	23	+0·43	0·40
Treatment	2	+0·89	0·95
Blocks	7	+0·14	0·67
Error	14	+0·32	0·50

Although there is some evidence of a slight connection between the two variants, the three coefficients for treatments, blocks and error are not significant. The utilization of carbohydrates in the production of new growth must obscure any relationship that would have been detectable had they been laid down as reserves.

The nitrogen content of the roots was also determined in order to ascertain whether it varied in the same way as did the carbohydrate content. No significant effects were found, the mean percentages being:—

Number of unpruned branches ..	0	3	6
Percentage	2·12	1·99	2·11

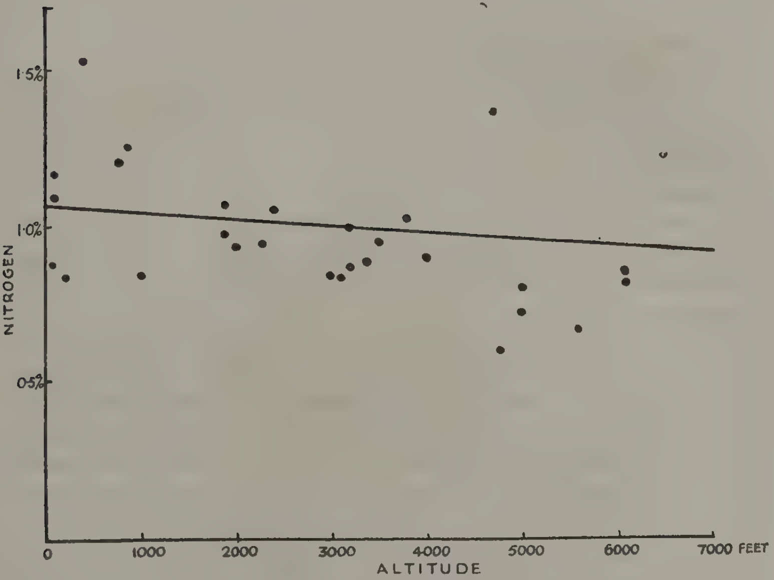

Fig. 2. The percentage of total Nitrogen, plotted against Elevation above Sea-level.

The value of z for treatment is only 0·1010, the appropriate value for P·05 being 0·6594. It appears therefore that the additional nitrogen required for the extra new growth made by the "lung" pruned bushes must have been absorbed from the soil. Unfortunately, no analyses were made of the new growth and no balance sheet can be drawn up.

A determination of the percentage of total nitrogen in tea roots from different elevations was made on aliquots of certain of the samples used for carbohydrate analysis. The regression of nitrogen on elevation (Fig. 2) based on thirty samples is:—

$$y = 1{\cdot}065 - 0{\cdot}002x.$$

The coefficient of x being insignificant, no real tendency is shown for the nitrogen content of the roots to vary with the altitude. The total nitrogen content of the roots thus provides no explanation of the altitudinal distribution of the death of branches or bushes after pruning, and there appears to be no reason for suggesting any direct connection between nitrogen level and Die-back.

DISCUSSION.

The relationship found between the carbohydrate level of the tea plant and the elevation at which it is grown appears to provide an explanation of the results obtained from the field experiments, while the altitudinal distribution of the so-called Diplodia disease is also explained if Gadd's (7) theory as to its nature is accepted. This theory has received support from the present series of experiments, which have shown that the death of complete bushes or of branches after pruning is reduced by methods of pruning which increase the leaf area and thereby the supply of carbohydrates during the recovery period.

At Talawakelle, at an elevation of 4,600 feet, "lung" pruning decreased the subsequent yield of the bushes. This is difficult to explain in the light of existing knowledge of the crop, but the decrease in the first year may be due, partly at least, to the temporarily unpruned branches not contributing to yield until later. In the second year the decrease was only 0·03 pounds greater than the significant difference, and much importance should not therefore be attached to it. At the lower elevation of Peradeniya (1,500 feet) no difference was detectable between the effect of "lung" pruning and "clean" pruning, which suggests that the former enhanced the yield sufficiently to compensate for the delayed yield of the temporarily unpruned branches.

The close connection between the weight of leaves on the bush and the yield of flush, which was found to exist at Kiriella until fourteen and a half months after pruning, suggests that an increase in the leaf area produced during the first phases of recovery from pruning may exercise a large influence on the subsequent yield of the bush, since its effects would be cumulative. This may in part explain the continued superiority in yield of the "lung" pruned plots over the "clean" pruned plots at this elevation.

The effects of "cut across" pruning as compared with "clean" pruning appear to be explicable on the same basis. The relative fall in yield at Talawakelle in the second year, where the carbohydrate reserves were sufficient to allow of normal growth, appears to run parallel to Winkler's (23) results on the grape vine, *Vitis vinifera,* in which the lighter the pruning the earlier the rate of growth fell off during the ensuing season.

The existence of a relationship between elevation and carbohydrate level appears to be due to several causes acting together, and at present it is not possible to estimate their relative importance with any exactness. It has been suggested that the young tea shoot, when normally harvested, has manufactured only about half of the quantity of carbohydrate used in its production, with the result that the amount available for storage is reduced. If the process of plucking is to be advanced as an explanation of the relationship between elevation and carbohydrate level, the yields obtained must also bear a linear relationship with elevation. But while yields at high elevations in Ceylon tend to be less than at low elevations no general rule can be drawn, many striking exceptions being found.

The mean rate of increase of dry weight per unit weight of a shoot is inversely proportional to the number of days taken to develop. Development at the higher elevations in Ceylon being slower, owing probably to the lower mean temperatures, the rate of dry weight increase is correspondingly diminished. If the average net rate of photosynthesis is not greater at low than at high elevations, the production of an equivalent weight of new shoot growth would cause a smaller drain on the carbohydrate supply at high than at low elevations; consequently more would be available for storage.

The length of the interval between successive prunings must also affect the carbohydrate reserves. Abundant evidence (17, 18) is available that in other plants frequent pruning or grazing diminishes the carbohydrate reserves to an extent that causes decrease in the growth rate or even death of the plant. Gadd (7) pointed out that the Diplodia disease of tea occurred at lower elevations in Ceylon, where the interval between prunings was shorter than at higher elevations. In addition, there is some evidence (19) that the average time taken for a shoot to mature to the harvesting stage may increase with the time that has elapsed after pruning. If so, the shoots produced later in the cycle would contribute more of the raw materials for their growth, and consequently the drain on the carbohydrate balance available for reserve would be decreased; this effect would be more marked in long cycles than in short. Variations in the length of the interval between successive prunings do not, however, provide a complete explanation of the relationship found. On several estates at elevations of 4,000 feet and more, only two years (or less) elapse between successive prunings as compared with the normal three years, but death or Die-back associated with starch deficiency has not been recorded.

The fact must not be lost sight of that the magnitude of the slope of the regression may be due to cumulative effects. If, as appears from the data presented, pruning results in growth being limited by lack of carbohydrate supply at low, but not at high elevations, no accumulation of reserves from cycle to cycle can occur in the former but it may in the latter.

The existence of a variation in carbohydrate reserves at different elevations, which cannot be attributed to cultural treatment, is shown, however, by the fact that iodine tests have indicated that in unplucked and unpruned tea seedlings the starch reserves of the roots are considerably less in amount at low elevations than at high.

It is probable that the variation in mean temperature of the air associated with elevation above sea level may influence the capacity of the bush to store carbohydrate reserves by reduction of the *net* daily assimilation balance. No survey of soil temperatures in Ceylon has been made, but it is probable that they vary with elevation in a way very similar to mean air temperatures. High soil temperatures enhance root respiration—a factor of considerable importance, owing to the length of the tropical night and to the high ratio of the root to the remainder of the bush in the cultivated tea plant.

None of the remaining factors for which data are available shows sufficient regularity of variation with elevation to account for the relationship, which must be attributed to the combined variations of cultural treatment and temperature.

Plants having small carbohydrate reserves are likely to be displaced by those with larger amounts of stored materials whenever insect or fungus attack leads to destruction of the leaf surface; and it is noteworthy that where tea cultivation has been abandoned in Ceylon, invasion by competing species is most successful at low elevations. At 5,000 feet an abandoned area occurs in which tea forms an almost pure association, whereas in another, at about 3,000 feet, the bushes were found to be much reduced in number, while a dense secondary jungle had sprung up. At lower elevations this is even more marked.

During the course of the investigations described assistance was received in the shape of materials and help from persons too numerous to mention individually; without these the work would have been materially impeded. In particular, the author is indebted to the Amalgamated Tea Estates Co., and to their agents Messrs. James Finlay & Co. and their Staff, for facilities at Kiriella, also to the Director of Agriculture and the Staff of the Department of Agriculture for facilities and active assistance in carrying out the experiment at Peradeniya.

SUMMARY.

The reaction of the tea plant (*Camellia Thea*) to three types of pruning has been studied at elevations of 4,600, 1,500 and 200 feet above sea level in Ceylon.

At 200 feet Die-back of frame branches and death of complete bushes occurs after pruning. This was reduced by those methods of pruning in which some leaves are left on the bush. A significant positional variance of Die-back was found to be associated with variations in the number of leaves on the pruned bushes. Rapid growth prior to pruning increased the amount of Die-back.

The number of primary shoots produced after pruning was affected by the method of pruning at 4,600 feet, but not at 200 feet above sea level. This is believed to be due to the occurrence of Die-back at the lower elevation. The growth of these shoots is affected by the number of leaves left on the pruned bush but not by the length of time they remain. A significant interaction between these two factors was found.

A correlation of $+0{\cdot}99$ was found between the yield of new shoots and the total weight of leaves over a period of fourteen and a half months after pruning.

The effects on yield of the three types of pruning were found to vary according to the elevation of the experiment and the time elapsed after pruning, significant treatment × year and treatment × elevation interactions being found.

The resulting yields are accordingly considered separately for each year at each of the three centres. In general, they show that the presence of leaves upon the pruned bush increased the yield during the two years subsequent to pruning at 200 feet, but decreased it at 4,600 feet. At 1,500 feet no effects were discernible.

Analytical data show that the method of pruning affected the carbohydrate level in the roots, in spite of the wide divergence in the amounts of new growth produced.

The differences in reaction to pruning at different elevations are considered in relation to the discovery of a connection between the amount of stored carbohydrate and the elevation at which the bush is grown. The linear regression $y = 11{\cdot}17 + 0{\cdot}20x$ (where y is the percentage of carbohydrate and x the elevation in feet above sea level) was found to account for 77 per cent. of the variance in carbohydrate content. Suggestions as to the reasons for the relationship are put forward and its ecological importance is discussed.

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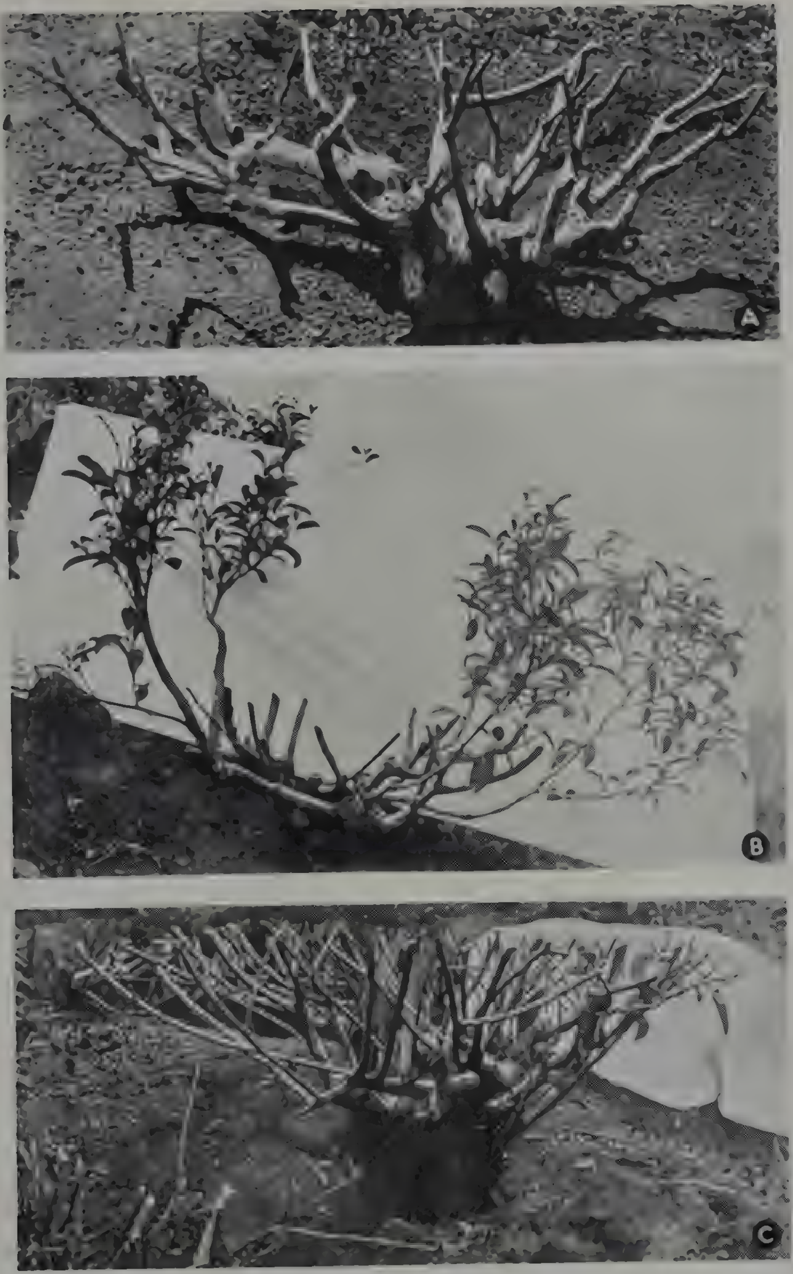

Pruned Tea Bushes. A, "Clean" pruned. B, "Lung" pruned. C, "Cut across"

STORAGE EXPERIMENTS WITH POLLEN OF CULTIVATED FRUIT TREES*

By B. R. NEBEL and M. L. RUTTLE

INTRODUCTION.

For horticultural purposes there is a distinct advantage in being able to store pollen from one year to another. By this means crosses can be made of varieties that are separated seasonally or geographically, and reserve pollen may be kept of such varieties as may be subject to winter killing or other injury.

PREVIOUS LITERATURE.

According to Zirkle (1935) accounts of some business contracts of the Hammurabi period (2000 B.C.) have been translated which show that even at that time the male flowers of the date palm were an important article of commerce. At an earlier date (2400 B.C.), in the fifth year of the reign of Gimil Sin, male dates were grown apart from female dates. It is evident that if trade in pollen existed at that time these early horticulturists must have given some thought to the problem of using pollen for the female flowers of their dates which remained viable for a useful period of time.

According to Popenoe (1913) "if date pollen is kept dry it preserves its value for a long time, and in some date growing communities it is the custom to save a small supply from each year to the next—a custom that may well be followed in America where females sometimes show surprising precocity in bloom. A pollination made in 1912 at the Mecca Experiment Station with pollen seven years old, sent from the Temple garden, was entirely successful. The elder Michaux reports, but apparently not of his own knowledge, that pollen had preserved its power during nineteen years in Persia. It can also be shipped easily from one region to another. Busreh often supplies pollen to a large part of the Persian Gulf."

Numerous papers have been published on the storage of pollen and its ability to germinate and fertilize after being kept under various conditions. Many of these investigations have been summarized by Pfundt (1910), Knowlton (1922), Holman and Brubaker (1926) and Doroshenko (1928).

Pfundt (1910) found that, with certain exceptions, pollen of numerous species stored in a dark place at a temperature of 17-21° C. and a relative humidity of either zero or 30% (maintained by sulphuric acid) showed, for the most part, considerably greater longevity than pollen kept at 90% humidity or at room temperature and uncontrolled humidity. Thus, pollen of *Prunus Padus* L. remained alive 15 days at 90%, 22 days at 60% and 181 days at 30% and at zero humidity. Similarly, pollen of *Prunus avium* L. remained alive 102 days at 30% humidity, 126 days at zero, and only 28 days at laboratory temperature and uncontrolled humidity.

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Holman and Brubaker (1926), in a parallel experiment, also found that of the forty-two kinds of pollen they tested the average longevity of thirty-two species stored in darkness at 17°-21° C. and a relative humidity of either 27·2% or 0·005% was approximately tripled as compared with that kept under laboratory conditions. In no case did the life of air-dry pollen exceed that of the same pollen stored at lower humidities. A humidity of 27·2% appeared, on the average, slightly better than that of 0·005% and much better than humidities of 94·2% and 63%. The greatest longevity noted was that of pollen of *Typha latifolia* L. which, stored over calcium chloride at 2% humidity, retained its germinative ability for 336 days.

Knowlton (1922) reports that a low temperature (0° to $-17°$ C.) favoured the longevity of pollen of *Antirrhinum majus* L.; under these conditions the maximum duration of germinative ability was 670 days and of fertilizing power 161 days. Corn pollen remained viable longest at a temperature of 5° to 10° C. and a humidity of 50% to 80%. The maximum retention of fertilizing power was 70 to 80 hours. Desiccation appears to be one of several factors that cause early death of pollen.

Sandsten (1909) reports slight germination of apple pollen kept dry at 7°-26° C. for 240 days. The lower temperature was probably of importance.

In Table I results that have been published concerning the longevity of apple, pear, plum and cherry pollen are summarized. This shows that the greatest longevities there recorded are for apple and plum kept at 7°-20° C. (Sandsten, 1909) and for *Prunus avium* (sweet cherry) stored over pure sulphuric acid (Pfundt, 1910).

MATERIAL AND METHODS.

The pollen of the different fruit trees growing either in the greenhouse or in the field was collected from unopened flowers or from flower clusters that had been protected by bags. After the anthers had been removed they were allowed to dehisce at room temperature in open Petri dishes protected from insects. After a period of from one to seven days the pollen was transferred to shell vials loosely stoppered with cotton wool. The vials were placed in desiccators in the Experiment Station apple storage room at 2°-8° C.; this store is usually kept dark except when lighted for entrance and removal of material.

TABLE I.

Published results concerning the longevity of apple, pear, plum and cherry pollen under various conditions of storage.

Kind of pollen.	Longevity.	Conditions of storage.	Investigator.
Apple	21 days	Collected and dried and placed in shell vials	Lewis & Vincent (1909).
Apple	240 days	Dry place, 7°-26° C.	Sandsten (1909).
Plum	180 days	,, ,,	,,
Pyrus Malus	70 days	Over pure H_2SO_4	Pfundt (1910).
Prunus avium	120 days	,, ,,	,,
Prunus Cerasus acida	81 days	,, ,,	,,
Apple	11 days	Air dry	Crandall (1912).
Apple	90 days	,,	Adams (1916).
Pear	70 days	,,	,,
Apple	Several weeks	Dried, in closed bottles, dark	Macoun (1916).
Apple Plum Cherry	40-50 days	In tin boxes wrapped in onion skin paper with tube of $CaCl_2$	Patterson (1929).

The desiccators were maintained at calculated humidities of 50%, 60%, 70%, 80%, 90% and 100% with sulphuric acid-water mixtures.

Pollen was germinated on 0·5% agar containing 10% or 20% sugar. Counts of germinating and non-germinating grains were made from 4 to 24 hours after the pollen was set up. Lacmoid stain was used to help to distinguish the pollen tubes.

The experimental error involved in studying pollen germination is generally considered to be high. Pollen from buds picked before the maturity of the sporocytes and obtained from flowers on twigs forced in the greenhouse in midwinter was found inferior to that ripened naturally. Germination on the microscope slide is at times erratic for unknown reasons. This primarily accounts for some of the irregularities shown in the appended graphs and table, and renders exact germination percentages of little value. The figures given represent averages from the 10% and 20% media where not otherwise stated.*

RESULTS.

Over a period of time the most favourable humidity for storage was found to be 50%. This is shown in the graphs, Figs. I to VI, in which the percentage germination of the pollen of McIntosh and Cortland apples and of Montmorency cherry, stored at 2° to 8° C. and I, at 100% ; II at 90% ; III at 80% ; IV at 70% ; V at 60% ; and VI at 50% humidity is plotted against the time of storage. An unbroken line represents the percentage germination of McIntosh pollen, a broken line that of Cortland, and a line of alternating dots and dashes that of Montmorency. Figs. I and II show that at the high humidities of 100% and 90% the ability of McIntosh and Cortland apple pollen to germinate was higher than at lower humidities during the first week.

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* In many varieties of fruit trees that have poor pollen it would possibly be more accurate to count only grains that appear viable and estimate the percentage of germination on this basis. This was not done, since this method is not generally followed.

This viability, however, fell off very rapidly so that at 100% humidity McIntosh pollen had lost its viability at the end of the third week and Cortland pollen at the end of the second week after the start (Fig. I). At 90% humidity McIntosh pollen was no longer viable at the end of the eighth week and Cortland pollen showed only 9% feeble germination at the end of the third week (Fig. II). At 100% humidity mould tended to grow in the pollen vials owing to their high moisture content. This was not observed at other humidities.

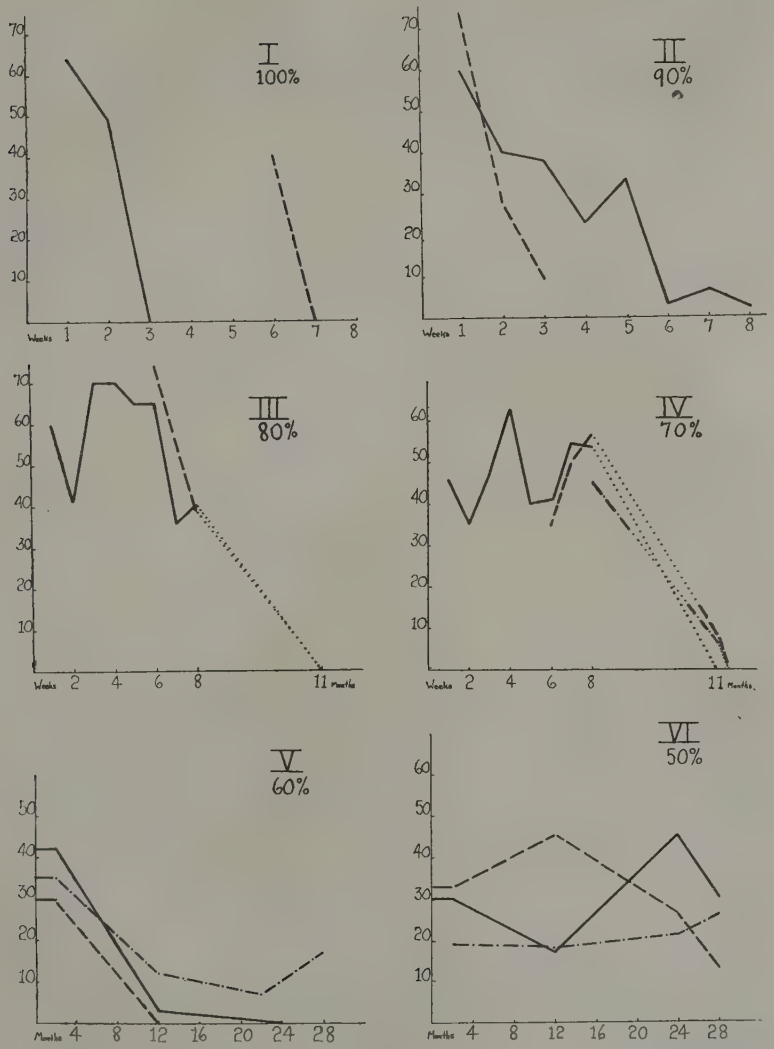
At 80% humidity the viability of the McIntosh pollen dropped from 70% to 40% in the first two months. The end point was not found, but lies somewhere between 2 and 11 months (Fig. III). At 70% humidity, 11 months is apparently nearly the end point of the life curve ; McIntosh pollen at this time was non-viable, Cortland pollen still gave 9% feeble germination, whilst Montmorency pollen gave 6% fair germination (Fig IV). In the two last named varieties there was practically no germination one month later.

At 60% humidity, percentage germination in the first two months was considerably less than at the higher humidities. Longevity however was increased, for a very small percentage of McIntosh pollen survived the first year and an average of about 12% of Montmorency pollen for two years.

At 50% humidity the proportion of viable pollen in the first two months was even less than at 60%, but approximately 30% of McIntosh, 12% of Cortland, and 25% of Montmorency pollen were still viable at the end of 28, 27 and 25 months respectively.

At 50% humidity McIntosh and Cortland pollen gave rather short crumpled germ tubes on germination at the end of the first year, despite which the pollen remained viable during the second year and at the end of it germination was similar to that of the previous year. At this humidity germinating pollen of Montmorency cherry gave long vigorous germ tubes at the end of the first year and still quite vigorous tubes at the end of the second year.

The highest viability recorded for McIntosh and Cortland apple pollen under these conditions of storage was 45%, and under any conditions, between 70% and 80% ; the highest viability for Montmorency cherry under these conditions was 26% and under any conditions 60%. When the highest viability at any time under these conditions of storage is compared with that after two years of storage it is evident that deterioration in viability is approximately



FIGS. I-VI. Graphs showing life curves of pollen of McIntosh apple (solid line), Cortland apple (broken line) and Montmorency cherry (line of alternate dots and dashes) stored in darkness at 2°-8° C. and at different humidities, viz. I at 100% ; II at 90% ; III at 80% ; IV at 70% ; V at 60% ; and VI at 50%. In each case percentage germination is plotted against time.

one-third for McIntosh and two-thirds for Cortland pollen, whereas the percentage germination of cherry pollen was actually higher than at the beginning of the experiment. Similarly, when the highest viability at any time under any condition of storage is compared with that after two years of storage, under the outlined conditions, there is an average deterioration of approximately two-thirds for McIntosh, four-fifths for Cortland and one-half for Montmorency.

TABLE II.

Unfinished test of pollen longevity, begun in the spring of 1934, reported upon in the summer of 1936. Humidity 50%, Storage temperature 2°-8° C.

Variety.	Period stored.	% Germ.	Period stored.	% Germ.	Period stored.	% Germ.	Type of Germ. tubes when last tested.
CHERRY (SOUR).							
Montmorency :							
50% humidity	1 week	19	9 mos.	18	25 mos.	24	Medium.
60% humidity	,,	35	,,	12	,,	12	Short.
CHERRY (SWEET).							
Emperor Francis (1935) ..	1 mo.	22	9 mos.	22	14 mos.	37	Short.
Elton	—	—	,,	9	,,	2	Long.
Average of 2 var.	,,	22	,,	15	,,	20	
APPLE.							
McIntosh (1934)	2 mos.	30	11 mos.	17	28 mos.	30	Medium.
Cortland (1934) ..	1 mo.	33	10 mos.	45	27 mos.	13	Short.
Pyrus coronaria (1935) ..	4 mos.	42	11 mos.	15	16 mos.	13	Long.
Kendall	,,	40	11 mos.	2	—	—	Short.
Tioga	—	—	11 mos.	10	—	—	Medium.
Wilson Red June	—	—	10 mos.	51	15 mos.	55	Medium.
Boiken	—	—	9 mos.	56	14 mos.	51	Medium to long.
McIntosh ..	4 mos.	50	,,	36	,,	52	Medium to long.
Sutton	—	—	,,	48	,,	60	Long.
Average of 4 last var.	4 mos.	50	,,	48	,,	54	
PEACH.							
Greensboro (1935)	1 week	75	11 mos.	15	16 mos.	22	Long.
Lola	—	—	,,	30	,,	68	
Average ..	1 week	75	,,	22	,,	45	
Average of 9 var. 1936	1 week	59	5 mos.	45	—	—	
PLUM.							
Grand Duke ..	—	—	11 mos.	65	16 mos.	74	Long.
Imperial Epineuse	—	—	,,	13	,,	12	Short.
Albion	—	—	,,	17	,,	50	Medium.
Hall	—	—	,,	62	,,	46	Variable.
Stanley	—	—	,,	39	,,	35	Long.
Reine Claude ..	—	—	,,	43	,,	35	Long.
Average ..	—	—	,,	39	,,	42	

TABLE II (*continued*).

Variety.	Period stored.	% Germ.	Period stored.	% Germ.	Period stored.	% Germ.	Type of Germ. tubes when last tested.
			PEAR.				
Gorham (1935)	1 mo.	56	10 mos.	77	15 mos.	77	Long.
Bartlett	—	—	,,	50	,,	55	Medium.
Louise Bonne de Jersey	—	—	,,	21	,,	9	Short to medium.
Covert	—	—	,,	53	,,	58	Long.
Duchesse d'Angoulême	3 mos.	77	,,	40	,,	6	Variable.
Beurré Giffard	—	—	,,	36	,,	55	Medium.
Ovid	—	—	,,	83	,,	87	Long.
Passe Crassane	3 mos.	73	,,	19	,,	7	Medium.
Phelps	—	—	,,	46	,,	54	Long.
Pulteney	—	—	,,	60	,,	32	Long.
Seckel	—	—	,,	29	,,	40	Long.
Willard	3 mos.	37	,,	45	,,	20	Medium.
Sta. 2175 (Bartlett × Beurré Giffard)	—	—	,,	40	,,	43	Long.
Average	3 mos.	61	,,	46	,,	42	
			GRAPE.				
Golden Muscat (1935)	—	—	7 mos.	21	12 mos.	36	Short.
Concord	—	—	,,	30	,,	23	Short.
Average	—	—	,,	25	,,	30	
			APRICOT.				
Doty (1936)	1 week	69	5 mos.	60	—	—	
F.P.I. 32465	,,	56	,,	15	—	—	
Seedling Apricot	,,	33	,,	5	—	—	
Toyahvale	,,	86	,,	47	—	—	
Average	,,	61	,,	32	—	—	

This indicates that at the comparatively low humidity of 50% the amount of viable pollen is less at any one time than at higher humidities, but the longevity is much greater. It is probable that the amount of germinating pollen at 50% humidity would increase if kept at 80% or 90% humidity for a couple of days prior to germination. This was successful with air-dry pollen.

Since it became apparent after a year that pollen would keep viable longer than had at first been expected, the experiment was extended to other samples of pollen as they became available from the general breeding work carried on at the Station. Thus, samples from different varieties of cherry, peach, plum, pear, apple and grape were stored in the spring of 1935 at 2° to 8° C. and at 50% humidity, this having been found in the first year to be the most favourable percentage for long storage.

The longevity test is not yet completed, for several lots of pollen still in store showed high germination percentage in their last test. It is intended to carry on the experiment until the actual death point is reached, but since the present results show figures already surpassing the best previously recorded for storage tests they are presented in incomplete form.

The results of these tests up to date are shown in Table II, which gives the percentage germination of the various kinds of pollen after different periods of storage. These figures show that pollen grains of 2 varieties of sweet cherry, 7 of apple, 2 of peach, 6 of plum, 13 of pear and 2 of grape have retained their viability for more than one year of storage at 2°-8° C. and 50% humidity, in addition to pollen of Montmorency cherry and of McIntosh and Cortland apples which can be germinated after more than two years of storage.

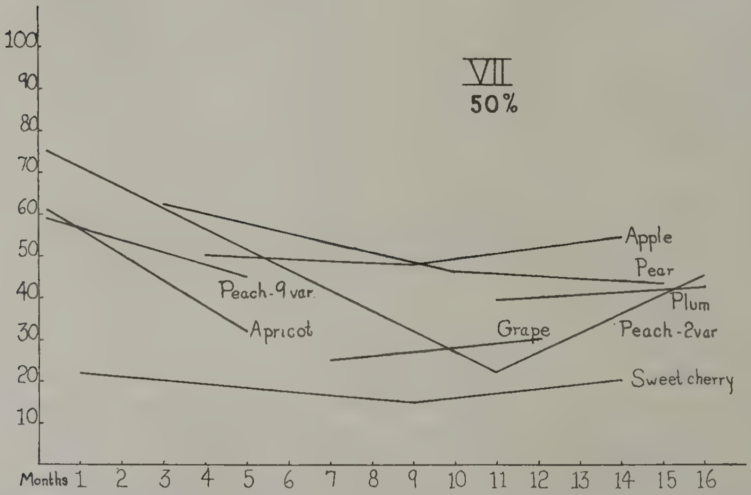


Fig. VII. Graph showing life curves of pollen of 2 varieties of sweet cherry, 2 of peach, 4 of apple, 6 of plum, 4 of apricot, 2 of grape, and 13 of pear, stored in darkness at 2°-8° C. and 50% humidity. Percentage germination in each case is plotted against time.

The average percentage germination of the cherry pollen at the beginning of this time (Table II, Fig. VII) is 22%, at the end 20%, the life curve running approximately parallel to the horizontal axis. The curve for Montmorency cherry (Fig. VI) over a similar period is very similar to that of the sweet cherry, the corresponding percentages being 19% and 18%. The apple curve is similar but higher, the corresponding percentages being 50 after 4 months and 54 at the end of 14 months. Peach pollen gave a high percentage germination in the first week (75%), so that the curve slopes more steeply, although the germination percentage at the end of 16 months is still 45.

Plum and grape pollen showed little variation in the percentage of viable pollen in the last five months of the test. The average germination of the pear pollen declined from 61% in the beginning to 46% at the end of 10 months and 42% at the end of 15 months. The apricot pollen showed a rather steep decline (61% to 32%) in the first five months of the test. The decline in the germination average of pollen of nine varieties of peaches over the same period was considerably less (59% to 45%). This may indicate that apricot pollen may not retain its viability so well as the pollen of the other fruits tested.

Pollen of certain varieties of fruit trees such as the Kendall apple and the Louise Bonne de Jersey pear showed practically no germination at the end of the recorded period and what did germinate was feeble, whereas pollen of many other varieties tested showed a relatively high percentage of germination and often long, healthy looking germ tubes. Nevertheless, Louise Bonne de Jersey pollen proved capable of securing fertilization.

In general it appears that pollen of many varieties of pear, plum (*domestica*), peach, sweet cherry and grape may be kept into the second year as readily as pollen of McIntosh and Cortland apples and Montmorency cherry. Pollen germination thus appears to a large degree to be a function of correct moisture content. This indicated that pollen which had become dried out badly in transit or during use in the orchard and had thus lost vitality might be revived by correct control of moisture and temperature. To test this, McIntosh pollen was kept in the laboratory until at the end of the fifth week when it failed to germinate. A portion of it was then placed in storage at 80% humidity, and after one week it gave 40% germination whilst another portion kept in the laboratory still failed to germinate. A similar sample of McIntosh pollen was kept in the laboratory for three weeks only and at the end of that time it still gave 33% germination. Parts of this were put into storage at 80% and 60% humidity. While the laboratory sample after two more weeks gave no further germination, the portions in storage at 80% and 60% humidity gave 59% and 16% germination respectively. Moreover, for the four weeks tested they continued to give as good germination as those samples put into storage three weeks earlier.

The biological reactivity of stored pollen was tested by fertilization trials in both years of the experiment. In 1935 the set of fruit obtained by using pollen of McIntosh and Cortland that had been stored for one year at 50% humidity at 2°-8° C. was approximately normal. The seeds in the fruits also appeared normal. In 1936 only one fruit set when 1934 McIntosh pollen was used on Jonathan. This fruit, however, contained five plump seeds. Twenty-seven fruits were obtained in 1936 from the use of one-year-old pollen of Boiken and Wilson Red June. The set was not as high as that obtained after using 1936 pollen but indicates comparatively high viability. No set occurred when 1935 pollen of *Pyrus coronaria* was used. The set obtained in 1936 by using 1935 pollen of Willard, Louis Bonne de Jersey, Passe Crassane and Duchesse d'Angoulême pears was consistently less than when 1936 pollen of the same varieties was used.

One fruit each from the following crosses made in the greenhouse in April 1936 was cut in July 1936, and the number of plump seeds present was found to be as follows:—

Louise Bonne de Jersey × Duchesse d'Angoulême, 1935 pollen	3	plump	seeds
Marshall × Louise Bonne de Jersey, 1935 pollen	1	,,	,,
Milton × Boiken, 1935 pollen	4	,,	,,
Orleans × Wilson Red June, 1935 pollen	6	,,	,,
Jonathan × McIntosh, 1934 pollen	5	,,	,,

DISCUSSION.

Holman and Brubaker (1926) and Pfundt (1910) found that humidities of zero and approximately 30% (maintained by the use of sulphuric acid) favoured pollen longevity, the latter percentage being slightly more advantageous. Knowlton (1922) found that a somewhat higher humidity and a moderately low temperature favoured the longevity of corn pollen. On comparing the results presented above with these it appears that for the pollen of the species and varieties of *Prunus, Pyrus* and *Vitis* tested, a humidity of 50% is possibly the optimum, the life curves becoming increasingly shorter and steeper as humidity is further increased (see 60% and higher humidity curves) and becoming shorter as humidity is further decreased (results of Holman and Brubaker and of Pfundt).

Both Holman and Brubaker and also Pfundt used a temperature of 17°-21° C. Knowlton found that the life of both corn and *Antirrhinum* pollen was prolonged at lower temperatures. It appears therefore that the temperature of 2°-8° C. used in the experiment described above was of value in extending the life of the pollen. A parallel experiment at 17°-21° C. and one at intermediate temperatures should be performed to ascertain the influence of temperature in the prolongation of life of the pollen.

The death of pollen has been variously attributed to desiccation, to exhaustion of stored food and to the weakening of essential enzymes. The extreme prolongation of life in the present experiment has been accomplished at an intermediate humidity of 50% in conjunction with a temperature slightly above freezing point. Approximately this temperature and this humidity were found most favourable for the prolongation of life of corn pollen (Knowlton 1922). The maximum vitality prolongation of corn pollen, however, was only

70 to 80 hours, so that factors other than humidity and temperature appear to be involved. Preliminary results indicate that pollen of certain varieties may lose viability more rapidly than that of other varieties under similar conditions of storage. What factors are involved in these particular cases and whether they are constant for the variety or affect only the particular sample of pollen used will not be known until further tests of these kinds of pollen in other years have been made. Thus, the almost complete loss in viability of Kendall and Tioga apple pollen (Table II) after eleven months is not necessarily bound up with the variety but may relate only to this particular sample of pollen.

Erratic pollen germination such as has been noted by other workers was frequently encountered and is particularly evident in Figs. I-IV as well as in Table II. This may be due to lack of uniformity in the sample, but other unknown factors may possibly be involved.

At high humidities, in particular at 90% and 100% as well as at room temperature and humidity, the percentage germination remained comparatively high for a period and then suddenly dropped to a very small figure where it remained for a time (Figs. I and II). Similar results were recorded by Holman and Brubaker, Pfundt and others working at similar humidities. On the other hand at 50% humidity, the percentage germination may remain practically uniform for a period of one year or more (Fig. VII, apple and cherry).

Germination on artificial media is generally accepted as a test of viability. Knowlton (1922) found that such germination of Antirrhinum pollen kept in storage did not indicate ability to bring about fertilization, hence pollen germination is only an approximate measure of its biological reactivity. In the present experiment stored pollen that was capable of germination was also capable of fertilization, but to a somewhat lesser degree than fresh pollen.

For horticultural purposes there is a distinct advantage in being able to keep pollen from one year to another. In the past, methods have been devised whereby pollen could successfully be transported for considerable distances (Patterson, 1929; Kellerman, 1915), but the maximum viability was within the seasonal limits so that pollen could not be sent from a later to an earlier blooming region. For genetical experiments it is not advisable to use pollen that has been stored for any length of time unless the fact that the normal mutation rate becomes greatly increased with increase of storage time is taken into account (Cartledge, Murray and Blakeslee, 1935). In horticultural plant breeding where recessive characters are often those that are being sought, a large-scale test of stored pollen against fresh pollen seems a tempting experiment.

In the present experiment varieties of pollen from plants belonging to the Rosaceae and Vitaceae alone have been used. It is scarcely to be expected that the life of such short-lived pollen as that of most of the Gramineae would be greatly prolonged by the conditions of storage described.

SUMMARY.

The period of life of pollen of apple and cherry, stored at 2°-8° C., increases with decreasing humidity from 100% to 50%. At 50% humidity it was found that pollen of apple and sour cherry still showed good germination after more than two years' storage. It is indicated that under these conditions the pollen of pear, plum, peach, sweet cherry and grape may also be kept for two years.

Stored pollen was used in fertilization tests and gave plump seeds wherever it was found to possess good vitality in the germination test.

Apple pollen which had apparently lost its viability after being stored in the laboratory for five weeks was revived by being placed in storage at 2°-8° C. and at 80% humidity.

ACKNOWLEDGMENT.

The authors are indebted to the Rockefeller Foundation for a grant in aid of their work to the N.Y. State Agricultural Experiment Station. Under this grant the counts during 1936 were made by Miss Iris Trump.

ADDENDUM.

After completing the manuscript of the foregoing paper the work of N. E. Pfeiffer* came to hand in which it was shown that pollen of *Amaryllis* and *Lilium* could be stored for more than five and seven months respectively at 10° C. and at optimum humidities varying between 35% and 65% according to the species. This work not only corroborates the present findings but indicates further—as was suggested in the text—that to ascertain the optimum condition of storage for any one kind (species, variety or even sample) of pollen, both humidity and temperature must be varied independently over a fairly wide range. It does, however, become increasingly likely that for practical purposes 50% humidity and a temperature of 5°-10° C. are conditions which merit wider application in any plant breeding work that necessitates storage of pollen.

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STOCK-SCION INCOMPATIBILITY IN CITRUS AND ITS CAUSE

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One of the main obstacles in breeding new stocks for *Citrus sinensis* in Java is the incompatibility of this species as a scion with many of the other species and varieties and with types newly raised by hybridization (Toxopeus 1936).

This incompatibility appeared for the first time in 1928 when the sour orange (*Citrus Aurantium*) was tried as a stock for djeruk manis, the native strain of *Citrus sinensis*. Later, the sour orange also proved to be incompatible as a stock with imported varieties of this species, such as Valencia orange, Hamlin orange, Washington navel orange and others.

At first it was thought that the sour orange strain used was not a good one and seed of *C. Aurantium* was imported from nurseries in California, Florida, Algeria and Palestine. The stocks grown from this seed were budded, with exactly the same result. Many off-type seedlings were also purposely budded, as it was considered that there might be a type amongst the segregates suitable as a stock, but although the " budlings " on a few of these seedlings grew much better than the majority yet all showed symptoms of decline within a year.

That this behaviour is a really serious handicap in breeding work is clearly demonstrated by the results assembled in Table I.

TABLE I.

Incompatibility of Citrus-hybrids as stocks for Citrus sinensis.

Female Parent.	Number of species used as male parent.	Total number of hybrids budded.	Number of healthy " budlings ".	Percentage of healthy " budlings ".
Citrus decumana (Shaddock)	10	about 1,255	0	0·0
Japanese Citron	9	866	68	7·8
Rough Lemon	4	54	8	14·8
Citrus aurantifolia (Lime) . .	4	20	1	5·0
Citrus Aurantium (Sour Orange)	2	18	0	0·0

From 1929 to 1932 several budding trials were made to elucidate the causes of this trouble and the results are presented in this paper.

FORM TAKEN BY THE FAILURE.

In all cases the buds take very well, and the first growth of the scion is as satisfactory as that of compatible combinations. The larger the stock used the better is the first growth.

"Budlings" of *Citrus sinensis* on sour orange stocks of normal size (one-and-a-half years old when budded) cease growth 2-3 months after budding; the leaves become stiff and slightly rolled like those of potatoes suffering from Leaf Roll disease (Fig. 1). Some time later, the terminal bud starts to grow again and many axillary buds along the shoot give rise to small twigs. The leaves, however, do not develop to normal size; they are chlorotic (mottled) from the beginning and drop very soon (Fig. 2). The plant gradually declines and, according to the original development of the scion, sprouting and leaf shedding may be repeated up to four or five times. Usually the "budlings" die within 8-12 months after budding.

In addition to a large number of hybrid stocks on which *Citrus sinensis* dies as rapidly as it does on sour orange, there are many combinations in which death does not occur nearly so rapidly. Many of these "budlings", indeed, have already survived for over five years, although their growth has always been rather unsatisfactory. These trees invariably possess more or less chlorotic leaves, and in serious cases the leaves soon fall, whilst many of the buds along the branches give rise to an excessive number of small twigs, as occurs with trees suffering from mottle leaf. As has been found elsewhere, however, such poorly growing trees may live for fifteen years and even longer.

REGIONS IN WHICH THE SOUR ORANGE FAILS AS A STOCK FOR *Citrus sinensis*.

A very remarkable fact concerning the failure of the combination *Citrus sinensis* scion on sour orange stock is that it occurs only in certain regions. This combination fails in the whole of Java, in the mountains as well as in the plains, in the very wet western part as well as in the very dry eastern province. According to Dr. Marloth, with whom the question was discussed during his visit to Buitenzorg, these "budlings" do not grow in South Africa, and in that country the symptoms of decline are identical with those in Java. In California, Florida, Brazil, Guiana, Spain, Italy, Sicily, Palestine, Morocco, Algeria, Tunis, the Philippines and Australia, however, the sour orange is very widely and quite successfully used, as it safeguards *Citrus sinensis* from attack by "Gum-disease", caused by a species of Phytophthora.

These differences in behaviour should give some indication as to the cause of the failure, but up to the present neither Dr. Marloth nor the writer has been able to deduce from this distribution any indication of the way in which this problem should be attacked. Soil differences might be a factor, but in

Java, with its numerous soil types, the combination would be expected to succeed at least in some places, and some success should be gained by manurial treatment in the nursery. In South Africa also, no indication in this direction could be found. The lack of a rest period cannot be a cause, because decline starts within three months after budding. Furthermore, in South Africa there is a rest period and in Java there is not. Differences in length of day cannot afford an explanation either, for in this respect South Africa does not differ from Australia, nor Java from Guiana.

PHYSIOLOGY OF THE FAILURE.

At the outset, budding experiments were carried out to find a way of eliminating what, at first, was thought to be the harmful effect of the stock. It was thought probable that the use of a variety compatible with both stock and scion, as an intermediate, would solve the difficulty, as holds good for some varieties of pear on quince stock (Bradford and Sitton 1929).

The combination of sour orange stock, Japanese citron (Ragpur lime ?) intermediate, and *Citrus sinensis* scion, however, appeared to be as incompatible as the combination without the intermediate. This result showed at once that the behaviour of citrus species is not comparable with the failure of pear on quince. In addition, a study of the bud union revealed a great difference between the two cases, that of the quince-pear combination being very poor and that of the Citrus absolutely normal.

In order to get an insight into the physiology of the failure a series of buddings was made in which the three species just mentioned were used in all possible combinations. The results of these experiments are represented diagrammatically in Fig. 3.

It appears that the trees die only when the scion species is *Citrus sinensis*, and either the intermediate or the stock is sour orange (Nos. 1, 11 and 12). The success of the tree (No. 7) with *Citrus sinensis* as an intermediate between the Japanese citron scion and the sour orange rootstock is particularly significant. This tree was built up by Mr. de Jong, the manager of the Ragoenan Horticultural Experiment Gardens, near Batavia. In the nursery certain large two-year-old sour orange seedlings were budded with *Citrus sinensis*, and in some cases the scion made such substantial growth that it was budded successfully with Japanese citron.

From this experience and from the fact that the first growth of *Citrus sinensis* on sour orange is proportional to the size of the stock, it was possible to conclude that the stock does not injure the scion, but that the scion has a lethal effect on the stock, probably starting at the moment when the scion begins to furnish assimilates to the stock.

This lethal effect can be explained in different ways. It may be that the foliage fails to produce some special foodstuff needed by the stock, or does not produce it in sufficient quantity. However, it may also be possible that the scion produces something toxic to the stock.

The crucial test was made by inserting two buds into some large sour orange seedlings, one of Japanese citron and the other of *Citrus sinensis*. Fig. 4 shows the result. Apparently the stock is killed by *Citrus sinensis*, in consequence of which the shoot of the Japanese citron also dies. In the writer's opinion this result can be explained only on the supposition that some strongly toxic action occurs from something manufactured in the leaves of *Citrus sinensis*.

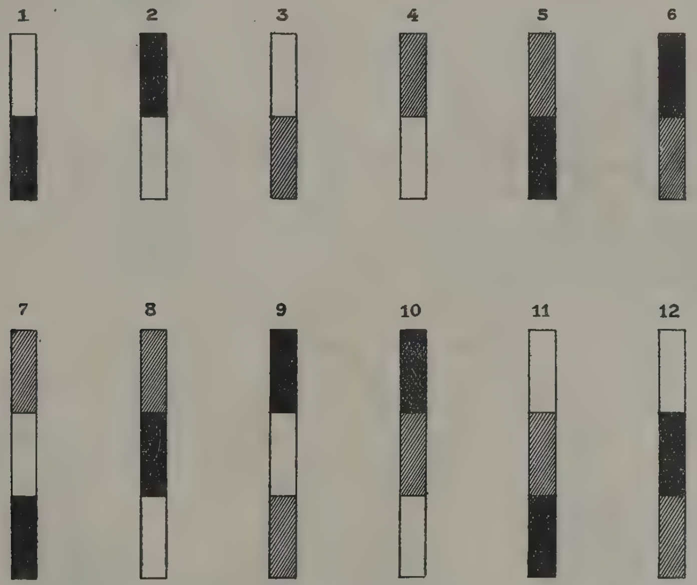

Fig. 3. Diagrammatic presentation of the results of a series of budding experiments. Only Nos. 1, 11 and 12 died, all other combinations grew very prolifically.
☐ *C. sinensis*. /// Jap. citron. ■ Sour orange.

This theory is supported by the results of a reverse experiment, in which certain vigorous three-year-old seedlings of *Citrus sinensis* and *Citrus nobilis* were each inarched into two one-year-old seedlings, one being Japanese citron and the other sour orange. The union of tissues was very good and the seedlings of the Japanese citron grew very prolifically so that one year after inarching they had almost doubled their original diameter (Fig. 5). The sour orange seedlings, on the other hand, did not grow at all and were nearly dead when inspected a year after inarching ; while at the union the stem was completely overgrown by the bark of the inarched tree.

The editors are indebted to the Imperial Bureau of Fruit Production for the following summary.

SUMMARY.

Sweet orange (*C. sinensis*) scions have proved incompatible with rootstocks of many other citrus species and hybrids in Java. On sour orange (*C. Aurantium*) stocks, in particular, the buds unite and grow normally for 2-3 months, but thereafter show various symptoms of decline, and usually die within 8-12 months.

In double-working experiments with sweet and sour oranges and with the Japanese citron, which is compatible with both the other species, it was found that the use of a compatible intermediate neither prevented nor delayed decline. It was further discovered from combining the three species in all possible positions that failure occurred only when the scion was sweet orange and the stock or intermediate sour orange.

The insertion of both sweet orange and Japanese citron buds into sour orange stocks resulted in death of the plants.

The inarching of sweet oranges with both sour orange and Japanese citron stocks resulted in failure of the sour oranges only.

These results indicate that the sour orange stock does not injure the sweet orange scion but suggest that the scion produces some substance toxic to the stock.

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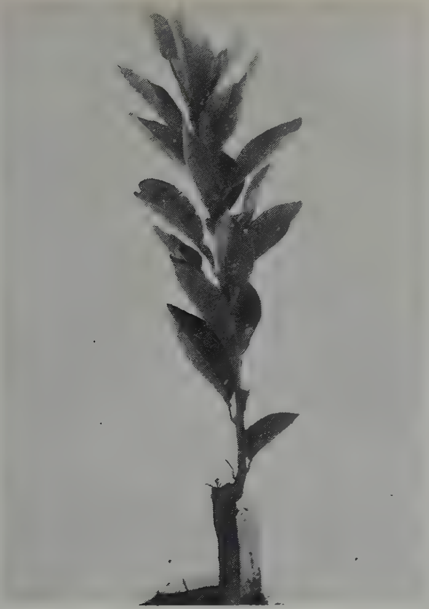

FIG. 1. First symptoms of decline of *C. sinensis* scion on sour orange stock.

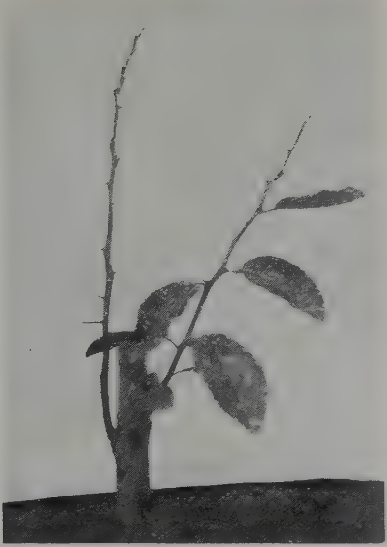

FIG. 4. Sour orange stock budded with *C. sinensis* (left) and Jap. citron (right), about six months after budding.

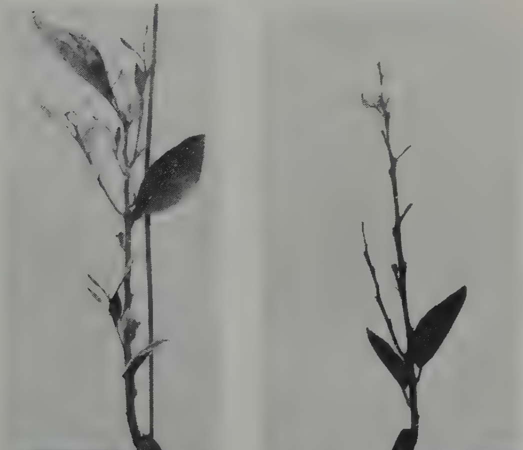

FIG. 2. Advanced stages of decline of *C. sinensis* scion on sour orange stock.

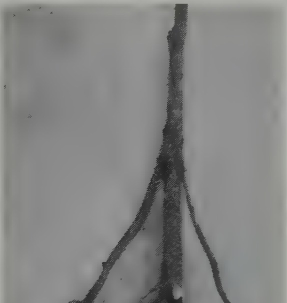

FIG. 5. Three-year-old seedling of *C. sinensis* inarched with Jap. citron (left) and sour orange (right), a year after inarching.

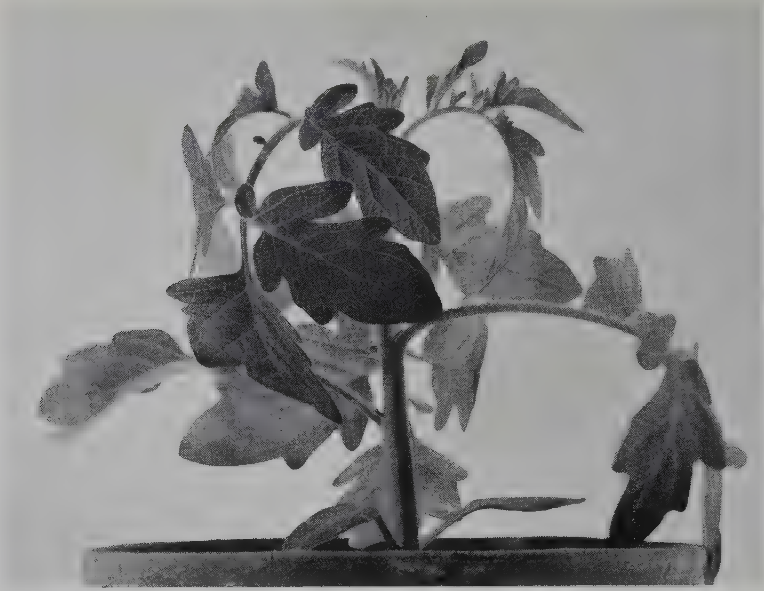

FIG. 1. Treated plant one hour after the first application of 0·1 per cent. of phenylacetic acid.

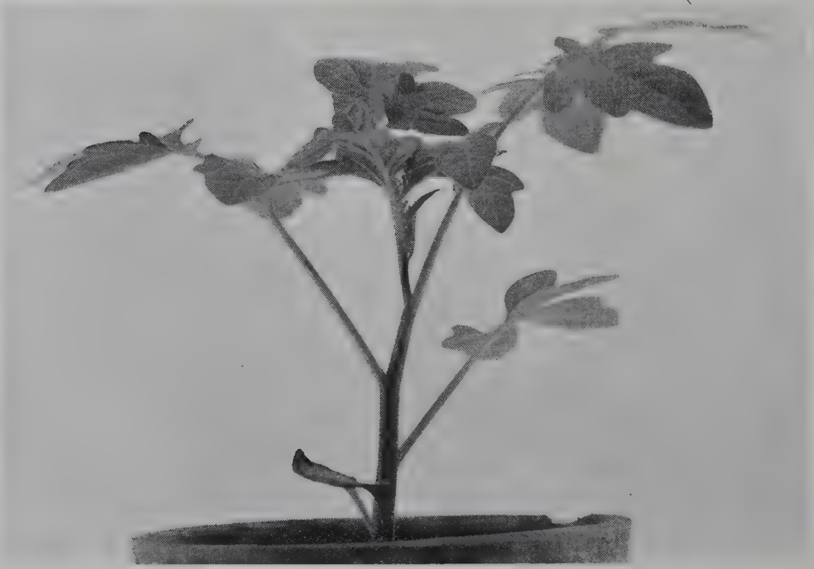

FIG. 2. Control plant one hour after the first application of tap water.

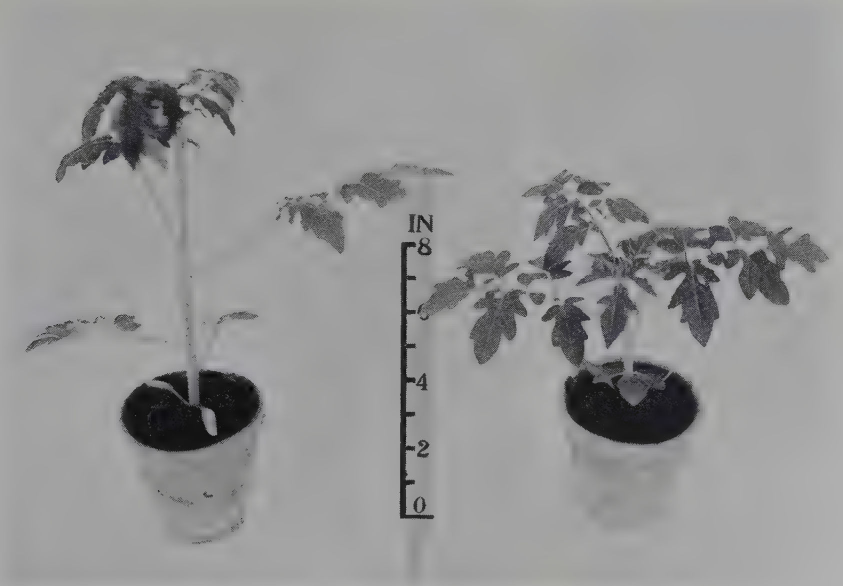

FIG. 3. After one week. The plant on the left was sprayed daily with 0·1% phenylacetic acid; that on the right was sprayed similarly with tap water.

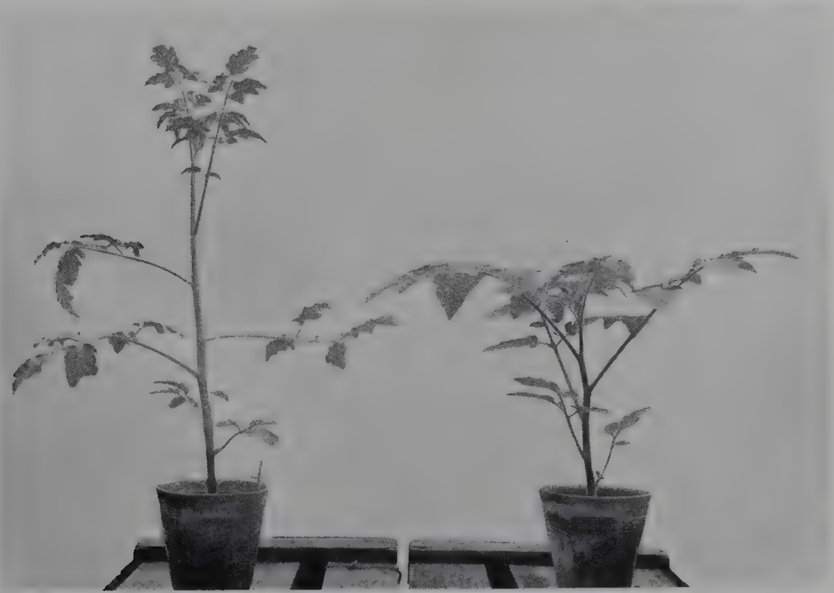

FIG. 4. After two weeks. The plant on the left was sprayed with 0·1% phenylacetic acid; that on the right is the control.

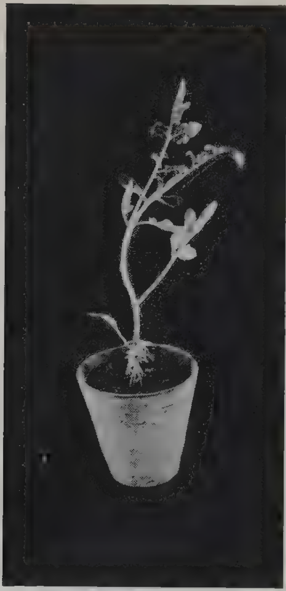

FIG. 5. Plant sprayed with 0·25% phenylacetic acid and then kept in a moist frame. Abnormally thick adventitious roots are present at the base of the stem.

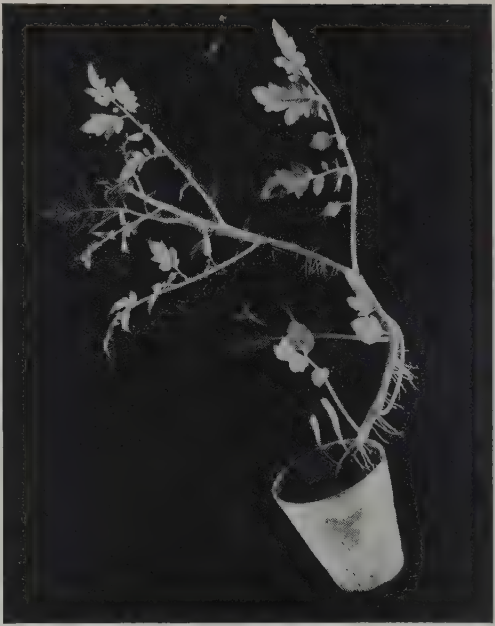

FIG. 6. Plant sprayed with 0·0625% phenylacetic acid. Adventitious roots occur over the whole length of stem.

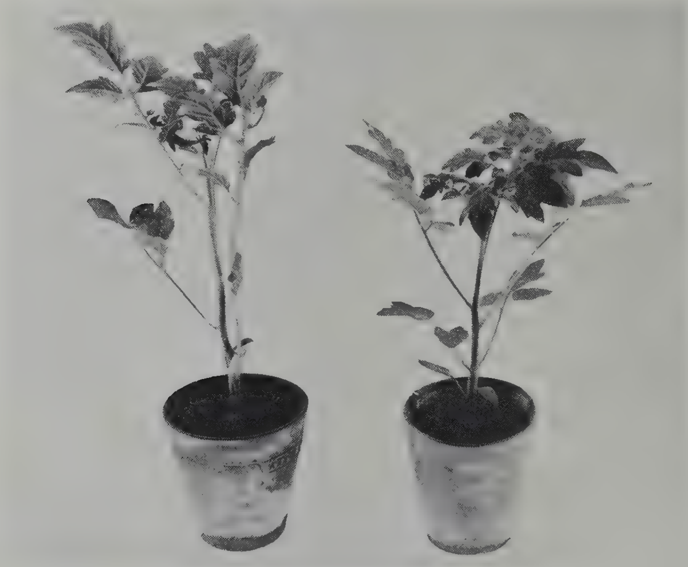

FIG. 7. The plant on the left was sprayed daily for one week with 0·1% indolebutyric acid. That on the right is the control. The leaves of the treated plant exhibit hyponasty.

THE EFFECT OF PHENYLACETIC ACID AND OF INDOLEBUTYRIC ACID ON THE GROWTH OF TOMATO PLANTS

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INTRODUCTION.

Arising from the discovery of a growth-producing substance in the coleoptiles of Avena by Went (6) and his school, and from the isolation of hetero-auxin (indoleacetic acid) by Kogl and his collaborators (5), the effects of a number of related organic compounds on the growth of plants have recently been described by workers at the Boyce Thompson Institute (1, 2, 3, 4, 7, 8,). Among the substances they have tested are phenylacetic acid and indolebutyric acid. They applied these chemicals to plants locally (dissolved in lanolin), as a solution in water added to the soil, or injected into the stem. The main responses of the treated plants were epinasty of the leaves, stem bending, swellings on the stems and petioles, initiation and stimulation of roots and retardation of growth.

One of the objections to the use of these substances in aqueous solution appears to be the loss of activity that ensues on keeping. It appears likely, therefore, that the active concentration of the substance within the plant decreases from the time of application onwards ; and it is probable that the maximum effect on the plant is never obtained by a single application. In the experiments now to be described, aqueous solutions of the substances were applied in repeated small doses by spraying the aerial parts of the plants. In this way the quantity of solution given to each plant could be controlled fairly accurately, and uniform distribution over the plant could be secured. Moreover, the active concentration within the plant was presumably kept at a fairly constant level. Some of the effects on the growth of tomato plants that were obtained by this method of application will now be described.

METHODS.

The substances used in these experiments were phenylacetic acid and indolebutyric acid. The solutions were prepared, as described by Hitchcock and Zimmerman (4), by dissolving the substances in two or three c.cm. of alcohol and making up to the required volume with tap water. The control solution consisted of tap water containing an equivalent amount of alcohol. In tests with tap water with and without alcohol it was found that the small amount of alcohol had no appreciable effect on the plants. The chemicals were obtained from the Eastman Kodak Company.

The tomato (*Lycopersicum esculentum*) was used as the experimental plant. The plants were raised from seed in a greenhouse kept at about 20° C. and the seedlings were pricked off into thumb pots and afterwards transferred to four inch pots. They were usually in their fourth leaf at the time of the first application of the given solution. The solutions were applied by spraying the aerial parts of the plants with a scent atomizer.

EXPERIMENTAL RESULTS.

Experiment 1. *The effect of spraying with phenylacetic acid.*

Twenty young tomato plants, each in its fourth leaf and as uniform as possible, were selected. Ten of them were sprayed daily at about 9.30 a.m. with a 0·1% solution of phenylacetic acid, while the other ten were similarly sprayed with tap water containing the same amount of alcohol; 25 c.cm. of solution were used at each application so that each plant received roughly 2·5 c.cm. The plants were in a greenhouse the temperature of which was about 20° C. and at the time of the experiment they were growing rapidly.

Epinasty of the leaves of the treated plants set in very rapidly and was clearly visible thirty minutes after spraying. Figs. 1 and 2 show a treated and a control plant one hour after the first application. By the following morning the leaves had recovered, and throughout the three weeks of the experiment they continued to give this epinastic response and recovery each day.

At the end of one week remarkable differences were apparent between the plants sprayed daily with phenylacetic acid and the controls sprayed with tap water. Fig. 3 shows a treated and a control plant at the end of this period.

The treated plants were much the taller of the two lots, their leaves were distinctly smaller, their stems thicker and their petioles longer than those of the controls. Swelling of the stem occurred, particularly at the nodes. These differences were still visible after treatment for two and three weeks. In addition, at the end of this period, the terminal bud had been completely inhibited in two of the treated plants, and no new leaves were arising. Fig. 4 shows a treated and a control plant after treatment for two weeks.

Three plants of each batch, selected at random, were harvested at the end of each week, and spraying of the remainder with 25 c.cm. of solution was continued. Measurements were taken of the lengths of the whole stem, the petioles to the base of the first pinna, and the internodes. The fresh and dry weights of root, leaf, stem and petiole were also determined.

TABLE I.

The effect of spraying tomato plants daily with 0·1% *phenylacetic acid.*

	After one week.			After two weeks.			After three weeks.		
	Phenylacetic Acid.	Control.	Ratio.	Phenylacetic Acid.	Control.	Ratio.	Phenylacetic Acid.	Control.	Ratio.
Stem Length. mm. ..	201	128	157	277	202	137	355	281	126
Petiole Length. mm. ..	48	35	137	52	42	124	50	40	125
Internode Length. mm.	27	16	169	28	22	127	31	20	155
Total Dry Weight. mg.	969	1,241	78	2,386	2,911	82	3,785	3,911	97
Leaf Dry Weight. mg.	444	701	63	1,006	1,585	63	1,408	2,113	67
Root Dry Weight. mg.	75	137	55	189	329	57	381	430	89
Petiole Dry Weight. mg.	156	169	92	442	417	106	628	552	114
Stem Dry Weight. mg.	293	234	125	749	580	129	1,340	816	164

In Table I the lengths of stem, petiole and internode, as well as the total dry weight, dry weights of leaf, root, petiole and stem at each harvest are given. Each number is the mean value for three plants. In the third column, in each case, the ratio of the value for the treated to that of the control plants is given. A ratio above 100, therefore, indicates an increase and one below 100 a decrease as compared with the controls.

It is clear from this Table that the lengths of stem, petiole and internode have all been increased by spraying the plants with phenylacetic acid. The ratio for length of stem gradually decreases after the first week, presumably because the inhibiting action on the terminal bud is beginning to have effect.

The total dry weight has slightly decreased, and the amount of leaf and root considerably diminished, while the amount of petiole and stem has increased.

TABLE II.

Showing the percentage of the Total Dry Weight present as Leaf, Root, Petiole and Stem.

Duration ..	After one week.		After two weeks.		After three weeks.	
Treatment ..	Phenylacetic Acid.	Control.	Phenylacetic Acid.	Control.	Phenylacetic Acid.	Control.
Leaf	45·8	56·5	42·2	54·5	37·5	54·0
Root	7·7	11·0	7·9	11·3	10·1	11·0
Petiole ..	16·1	13·6	18·5	14·2	16·7	14·1
Stem	30·4	18·9	31·4	20·0	35·7	20·9

The ratio of the dry weights of the leaves remains practically constant throughout the experiment, while the ratios for root, petiole and stem continue to fall. It would appear, therefore, that for the duration of the experiment, at any rate, the amount of leaf formed was maintained at a new lower level. The amount of stem, petiole and root continued to increase with time relative to the controls, as is shown by the increasing value of the ratio. That the amount of root increases again after first decreasing may be explained by the fact that, although root growth is retarded by the treatment, new roots are initiated later at the base of the stem, and these gradually compensate for the retardation. The total amount of growth was not greatly affected during the period of the experiment, the reduction in the amount of leaf being counteracted by the increased amount of stem and petiole. It is difficult to see how this state of affairs could be maintained for long, for it would seem inevitable that the reduction of leaf must eventually diminish the amount of capital added to the plant by photosynthesis, unless, indeed, the photosynthetic efficiency of the leaves becomes increased by the treatment. It would therefore be expected that the total dry weight of the treated plants would fall considerably.

In Table II the dry weight of each organ expressed as a percentage of the total dry weight is shown. The decrease in the proportion of the total dry weight accounted for by the leaf and root, and the increase in that accounted for by the stem and petiole is clearly seen. A reduction in the percentage of leaf must necessarily raise the percentage of the total present in the other organs, but the ratios given in Table I show that the amounts of stem and petiole have increased in spite of the decrease in the amount of leaf. It would seem, therefore, that one of the primary effects of the treatment is to alter the relative distribution of material between the different organs of the plant.

EXPERIMENT 2. *The effect of spraying once weekly with phenylacetic acid.*

Four plants were sprayed on the first and the seventh days with 0·1% phenylacetic acid, while four control plants were similarly sprayed with tap water. The plants were harvested on the fourteenth day. In Table III the percentage of the total dry weight present as distributed in each organ is given. It is seen from this Table that the effect of the weekly spraying has been very slight. Alteration in the balance of the plants is, however, in the same direction as in Experiment 1, there being a reduction in the proportion of the total dry weight present as leaf and root, and an increase in that present as petiole and stem.

TABLE III.

Percentages of Total Dry Weight present as Leaf, Root, Petiole and Stem.

Treatment.	Phenylacetic Acid.	Control.
Leaf ..	47·0	48·9
Root ..	12·7	13·4
Petiole ..	17·0	15·8
Stem ..	23·3	21·9

EXPERIMENT 3. *The effect of varying the concentration of phenylacetic acid.*

The concentrations of phenylacetic acid used in this experiment were 0·5%, 0·25%, 0·125% and 0·0625%. Tap water was used for the controls. Eight plants were sprayed daily with each solution, and two plants of each batch were placed in a moist frame to encourage the production of adventitious roots. Three plants from each group were harvested on the seventh day and three on the fourteenth day.

There was pronounced injury to the leaves with the highest concentration, large patches of the laminae shrivelling and drying up. There was slight spotting of the leaves with the next lower concentration; but no visible damage with the two lowest concentrations.

The plants that were placed in the humid frame received only four applications. After the fourteenth day those sprayed with the highest concentration

TABLE IV.

Showing the effect on the dry weights of spraying with different concentrations of phenylacetic acid.

Time ..	After one week.								
Concentration of phenylacetic acid.	0·5%	Ratio.	0·25%	Ratio.	0·125%	Ratio.	0·0625 %	Ratio.	Control.
Total Dry Weight mg. ..	281	64	299	68	352	80	431	98	441
Leaf Dry Weight mg. ..	151	57	147	56	163	62	226	86	263
Root Dry Weight mg. ..	17	55	20	65	22	71	31	100	31
Petiole Dry Weight. mg.	39	67	45	78	74	128	61	105	58
Stem Dry Weight mg. ..	74	83	87	98	94	106	112	126	89

Time ..	After two weeks.								
Concentration of phenylacetic acid.	0·5%	Ratio.	0·25 %	Ratio.	0·125%	Ratio.	0·0625 %	Ratio.	Control.
Total Dry Weight mg. ..	376	23	788	48	890	54	1,583	96	1,652
Leaf Dry Weight mg. ..	178	19	319	34	375	40	803	86	931
Root Dry Weight mg. ..	19	10	55	30	67	36	138	75	185
Petiole Dry Weight mg.	65	30	141	64	162	74	259	118	220
Stem Dry Weight mg. ..	114	36	273	86	286	90	390	123	317

were dead. With the 0·25% solution, abnormally thick roots had appeared, but at the base of the stem only. The best development of roots occurred with the lowest concentration used; here roots were normal and appeared over the whole stem. Figs. 5 and 6 show the roots present on the stems of plants sprayed with 0·25% and with 0·0625% solutions respectively. The controls had no adventitious roots. Some curvature of the stems occurred with the plants kept in the frame, but very little with those on the bench.

In Table IV the dry weights of the whole plant and those of leaf, root, petiole and stem are given, each figure being the mean for three plants. The ratio of the experimental to the control weights is given in each case. It is seen that the total growth is more and more reduced with increasing concentration. The amount of leaf and root decreases with increasing concentration, while the amount of stem and petiole increases with low but is reduced with higher concentrations. About 0·1% seems to be the most effective concentration for increased stem growth, while with decreasing concentration there is less and less retardation of leaf and root growth. It is possible that with lower concentrations than those employed, leaf growth might be increased.

EXPERIMENT 4. *The effect of spraying with indolebutyric acid.*

Twelve plants were selected; six were sprayed daily with a 0·1% solution of indolebutyric acid and an equal number with tap water.

Fig. 7 shows a plant sprayed with indolebutyric acid and a control plant after treatment for one week. After one week this acid also caused increased height of the plants, and the lengths of the petioles and internodes were also greater than those of the controls. Epinasty and recovery also occurred after each application as with phenylacetic acid treatment; but with indolebutyric acid the petioles curved upwards after recovery to a greater degree than usual, so that the leaves became almost parallel to the main stem and the plants had a peculiar tufted appearance. The stems of the plants treated with indolebutyric acid were also swollen and, as after treatment with phenylacetic acid, the swelling was especially noticeable at the nodes. The leaves on plants treated with indolebutyric acid were distinctly smaller than those of the control plants.

At the end of seven and of fourteen days, respectively, three plants from each batch were harvested, measurements of the lengths of stem, petiole and internode were made and the fresh and dry weights of leaf, root, petiole and stem determined. These data are presented in Table V, each figure being the mean for three plants. In this instance the length of the petiole was measured to the base of the topmost pinna. The ratio of the value for the treated to that for the control plants is also given.

The inhibition of the terminal bud was more rapid with indolebutyric acid than with phenylacetic acid, so that after two weeks the control plants had

TABLE V.

The effect of spraying tomato plants daily with 0·1% indolebutyric acid.

	One week.			Two weeks.		
	Indole-butyric acid.	Control.	Ratio.	Indole-butyric acid.	Control.	Ratio.
Length of Stem mm.	156	115	136	191	185	103
Length of Petiole mm.	63	49	129	94	79	119
Length of Internode mm.	24	19	126	31	21	148
Total Dry Weight mg.	483	477	101	1,035	1,325	78
Leaf Dry Weight mg.	213	302	71	370	736	50
Root Dry Weight mg.	43	33	130	175	126	139
Petiole Dry Weight mg.	82	57	144	187	203	92
Stem Dry Weight mg.	145	84	173	303	260	117

again almost reached the same height as the treated ones. This is shown in the Table by the change of ratio from 136 at the end of the first week to 103 at the end of the second. The lengths of the petioles and internodes had increased.

In Table VI the percentages of the total dry weight present as distributed in each organ is given. It is seen that the effect on leaf, petiole and stem was

TABLE VI.

The effect on the percentage of the total dry weight present as leaf, root, petiole and stem, of spraying tomato plants daily with indolebutyric acid.

	One week.		Two weeks.	
Treatment	Indolebutyric acid.	Control.	Indolebutyric acid.	Control.
Leaf	44·1	63·4	35·7	55·5
Root	9·0	7·0	16·9	9·5
Petiole	17·0	12·0	18·1	15·3
Stem	29·9	17·6	29·3	19·6

very similar to that produced by phenylacetic acid, but the outstanding difference is that with indolebutyric acid the amount of root had increased after treatment for one week and increased still further after two weeks. This is shown in Table V by the rising value of the ratio.

DISCUSSION.

By the spray method of applying the growth substances to the aerial parts of the plants uniform entry of the substance is secured so that no bending of the stem occurs. Epinasty of the leaves still occurs, however, and this greater growth of its upper side is perhaps a reflection of the bilateral symmetry of the petiole. The greater initial growth in height of the treated plants may be due to increase in size of the cells.

The experiments described have shown that with the treatments given, the growth substances cause no increased growth of the plant as a whole but exert, on the other hand, a reducing effect. With the appropriate concentration, this reduction is minimal. On the other hand, the treatments seem to have a very large effect on the way in which the plant capital is distributed. The substances do in fact appear to control the amount of plant capital that shall go to the making up of each particular organ, without altering the total amount of plant material.

Of course greater reduction of leaf growth may be due to more rapid entry into the leaves, so that they actually receive a higher concentration than the other parts of the plant ; thus, with a lower concentration it may be possible to stimulate leaf growth also. In the short period experiments here described the reduction in the amount of leaf has apparently not had time to affect the total growth of the plants to any great extent. This applies only to the lowest concentrations. If the experiments were continued for a longer time it is difficult to see how this state of affairs could continue, since the greater part of the capital added to a plant during its growth is due to the materials manufactured in the leaves, and it would seem inevitable that the amount of this added capital must be less if the leaf size is reduced.

In several cases it was noticed that the terminal bud was eventually inhibited by the treatment, and if the plants had continued to grow, the controls would probably have soon exceeded the treated plants in length.

That swelling of the stem occurred especially at the nodes is perhaps explained by supposing that the substance after entering the leaves passes down the petiole into the stem and that a rather higher concentration of it occurs at the point of junction of the petiole and the stem.

The water content of the treated plants was always greater than that of the controls, and this may be due to a reduction in transpiration rate brought about by the smaller leaf area.

In the coleoptile of Avena the auxins appear to be continuously manufactured whilst growth is taking place, and it is probable that the aerial parts of plants are continually manufacturing small quantities of growth substance. By periodically spraying with growth substances this normal supply is perhaps augmented in a fairly natural way.

In conclusion the writer wishes to thank Professor V. H. Blackman, at whose suggestion this work was carried out, for help and advice. He also wishes to thank the Director of the East Malling Research Station, Mr. R. G. Hatton, for his kind help and for the facilities afforded at East Malling. To Mr. M. C. Vyvyan, for advice and helpful criticism, and to Mr. R. Bray, for assistance with the experimental work, thanks are also tendered.

SUMMARY.

1. A method of applying phenylacetic acid and indolebutyric acid in the form of a spray to the aerial parts of tomato plants is described.

2. Epinasty of the leaves, swelling of the stems and petioles and initiation of roots on the stems were obtained by this method, i.e. results similar to those obtained by other workers who applied these substances locally (dissolved in lanolin) or supplied them in aqueous solutions to the soil.

3. A daily application for one week of either phenylacetic or indolebutyric acids caused increase in height, and increase in length of the internodes and petioles as compared with control plants similarly sprayed with tap water. In addition, it induced differential responses in various parts of the plants; with phenylacetic acid leaf and root growth was depressed, while stem and petiole growth was increased; with indolebutyric acid leaf growth was depressed, and root, stem and petiole growth was increased.

4. Growth of the apical bud was gradually inhibited, indolebutyric acid acting rather more quickly than phenylacetic acid in this respect.

5. With phenylacetic acid the relative amount of leaf, as dry weight, in the treated plants as compared with the controls, remained practically constant after two and three weeks' treatment when sprayed with 0·1% solution. The relative amount of stem and petiole continued to increase. The amount of root began to increase again after one week, owing to the fact that new roots were initiated at the base of the stem.

6. The water content of the plants sprayed with phenylacetic acid and with indolebutyric acid was always greater than that of the controls.

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THE REINVIGORATION OF APPLE TREES BY THE INARCHING OF VIGOROUS ROOTSTOCKS

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THIS investigation was begun by Hearman in collaboration with R. G. Hatton as part of her studies at East Malling on the behaviour of Northern Spy as a rootstock. Elsewhere (1, 2) it has been reported that in field tests at East Malling the variety Grenadier when worked on Northern Spy has shown marked lack of vigour as compared with its behaviour on many other varieties of layered rootstocks. It has also been recorded (2, 4) that some other scion varieties show similar lack of vigour when worked on Northern Spy under many conditions overseas. Attempts have therefore been made to overcome this lack of vigour in established trees by inarching another (vigorous) root system to the tree trunk, to supplement and eventually largely replace the existing root system.

There are a considerable number of references (especially in American pomological literature) to the use of inarching, often coupled with bridge grafting, for treating fruit trees (both deciduous and citrus) that have been girdled by mice or by some form of collar rot, or have suffered winter injury to the roots through low temperatures.

There is plenty of information in these reports about the methods of inarching and about the purpose and success of forming an additional line of communication between the trunk and the soil. There appears to be no mention of the subsequent influence of these inarched stocks upon the original tree, though it is evident that they have had the desired effect of saving the life of the tree in the first season. Concerning lemon trees injured by gophers, Hodgson (5) reports that "most of the trees treated by this method (i.e. inarching) have shown satisfactory recovery. When applied soon after injury, in nearly all cases the trees have suffered no appreciable nutritional disturbance and no diminution of crop whatever."

In 1930 Hatton was shown striking examples of the effects of such inarching of seedling apple rootstocks into the trunks of Sturmer Pippin trees on Northern Spy rootstocks in the orchards of Mr. F. Walker at Lalla, Tasmania. The method used and the subsequent behaviour of these trees were described by P. H. Thomas (8) in 1933. He says that as far back as 1918 "many orchardists realized that blight-resistant trees (i.e. those worked on Northern Spy) were giving a poor response to cultural methods which had proved successful under similar conditions with trees worked on the seedling stock". "It was at this period", he continues, "that a number of growers considered the process of inarching as a means of reinforcing their unsatisfactory trees. It was believed that with the introduction of a more vigorous rootstock the rooting range would be extended and improved growth would result.'' A similar instance of the beneficial effects of inarching in Stanthorpe, Queensland, is briefly mentioned by J. M. Ward (10). Work of an experimental nature had actually been started on the Tasmanian State Experimental Orchard in 1918 but unfortunately the area was subsequently disposed of and no accurate results were obtained. Nevertheless, practical methods of affecting the '' inarch '' and '' reinforcement '' had been established, and in 1928 Thomas (7) actually figured a young seedling rootstock planted and inarched into the trunk of a tree on Northern Spy roots. The general statement is made that '' a number of stocks can be used in this way to reinforce a large tree ; in a few years they will establish themselves as a succession of feeders and develop a new rooting system ''. Unfortunately, however, no numerical data are available, and the use of '' strong apple seedlings '' of unknown origin left this very interesting experiment inconclusive. Again, there were no strict '' controls '' to the commercial trees in the Lalla Orchards, though the use of seedlings of varying age or vigour as inarches on each side of individual trees gave rise to very striking instances of '' lop sided '' reinvigoration of growth.

The use of this method, therefore, in studying the efficiency of a rootstock such as Northern Spy on a given site, and particularly with clonal material, called for intensive investigation.

Thomas (8) stated that although no improvement was evident '' until at least five or six years after the operation, once a vigorous type of introduced stock is established, the tree generally shows a response to the treatment ''. In view of this supposed lapse of time before the effect could be detected, special methods were adopted at East Malling to try and accelerate the results, particularly in view of the circumstance that Hearman's stay in England would necessarily be comparatively short (2½ years).

TREE MATERIAL EMPLOYED.

A small orchard of bush trees of Grenadier upon four varieties of layered rootstocks of very different degrees of vigour was used. The previous history of these trees has been reported in detail elsewhere (2) ; it will be sufficient here, therefore, to give an idea of their relative vigour by referring to their trunk measurements, which were as follows:—

Mean Area of Cross Section of Stems of Grenadier trees 12 years old.

Rootstock.	*No. available.*	*Sq.cm.*
Bristol OF5	9	89·2
Malling No. II	9	68·7
Northern Spy	6	52·6
Malling Crab H	6	39·9

The trees on both Northern Spy and Crab H were significantly less vigorous than those on Bristol OF5. In addition, they were very variable and generally showed very severe leaf scorch which was not apparent on the trees on Bristol OF5 and Malling No. II. Four of the most stunted and scorched trees on Crab H and three on Northern Spy were chosen for the inarching operation. The rootstock chosen was Malling No. XVI, a clonal layered rootstock already known to impart vigour to all the scion varieties that had been grafted directly on it (3). Sturdy rootstocks that had been bedded in nursery rows for two seasons after removal from the layer bed, were purposely chosen.

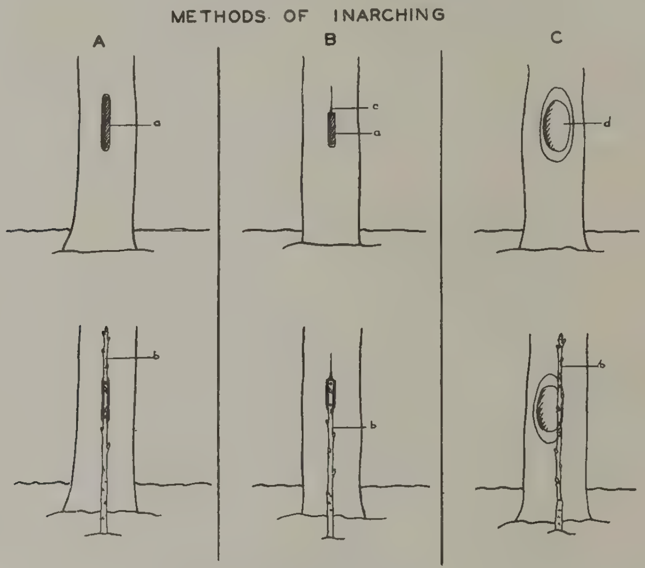


FIG. 2. Diagram illustrating the three methods of inarching used. (See pp. 378-379.)

When the rootstocks of No. XVI selected for inarching were planted towards the end of February 1934 close to the bases of the experimental trees, care was taken not to disturb the existing roots of the trees. Fig. 1 shows how, wherever possible, the young rootstocks were planted actually between and beside the main framework roots of the original Northern Spy rootstock.

METHODS OF INARCHING.

Three methods of inarching were tried, and equally good unions were secured with all of them. They are illustrated in Fig. 2, and are explained in detail below:—

A.—A slot (a), about six inches long and the exact width of the rootstock, was made in the bark of the trunk, exposing the wood. The ends of the slot were sloped off to allow the rootstock to fit in snugly. A slice was taken off the side of the rootstock (b) facing the tree, so that when fitted into the slot, the cambiums of rootstock and trunk should be in contact. The rootstock was then held in position with a couple of half-inch iron nails. The junction was smeared with clay, tied with string, and waxed. The clay and string were extra precautions, and it is probable that waxing combined with nailing would have been sufficient to secure good union.

The top of the shoot was left on the rootstock in this case in order to encourage root development, but it was removed at the end of the first growing season. This method is quick and makes a very neat union.

B.—This is an adaptation of the "rind" or "inverted T" graft. A slot (a), about four inches long, was cut in the same way as for method A. The lower end of this slot was sloped as before, but at the upper end a slit (c) was made in the bark about two inches long. The rootstock (b) was sliced to fit the slot and its top was cut off and trimmed as for a rind graft. This upper end was inserted under the bark below the slit (c) and gently pushed up till the rootstock lay in the slot (a). Small iron nails were used to hold the rootstock in position, and the wound was treated as in method A.

C.—A slice (d) was taken off the trunk of the tree and another off the side of the young rootstock, thus providing two flat surfaces. The cambiums of tree and rootstock could then be fitted together, but along one side only, as a rule, because the slice on the trunk was generally wider than that on the rootstock. The rootstock was nailed in position, and the wound was treated as in method A. This method is the quickest of the three described but often necessitates making rather a large wound in the trunk.

ACTUAL TREATMENT OF INDIVIDUAL TREES.

As has already been mentioned, special methods were devised in the hope of obtaining demonstrable results in two seasons. The seven most debilitated trees and a number of very sturdy, vigorous rootstocks were chosen. The plan was to insert these vigorous rootstocks into one side or portion of a tree, in the hope of obtaining the lop-sided reinvigoration effect that had already been observed in Tasmania. For this reason sometimes one rootstock was inarched directly into a single branch of a tree; at others two, and generally three, rootstocks were inarched into one side of a tree in the hope of obtaining a differential effect on two or more particular branches. Thus, each tree was to form a "plot" in itself, and certain branches were intended to act as

" controls " for the others, which, it was hoped, would be influenced by the inarched No. XVI rootstocks. For convenience, these are here called " treated " branches.

In addition to the seven bush trees, a single half-standard tree, of the same variety (Grenadier on Northern Spy) on another plot, was similarly inarched at the same time with three No. XVI stocks on one side of the trunk by method A. This tree, shown in Fig. 1, was treated in this way in preparation for a detailed root excavation, the results of which have already been published (4), but it will be dealt with again later in the present paper.

FIRST OBSERVATIONS.

In 1934 and 1935 observations were made by Hearman, and one " control " branch, away from, i.e. not immediately above the inarched stocks, was selected at random on each tree for comparison with the " treated " one directly above the inarched rootstocks. The girth and new wood growth of each individual " control " and " treated " branch were recorded in the two seasons. In addition, both at the beginning and at the end of the growing seasons of 1934 and 1935, a morphological census (9) of the growths was made in order to ascertain whether the proportion of primary bearing growths to vegetative growths had been altered by the treatment.

Preliminary Results.

When the records were examined, there were, generally speaking, no striking differences between the amounts of growth of the branches ; but, by the end of the second season, the effect in two out of the seven trees was readily seen by mere inspection of the trees themselves. On one tree, which had had two rootstocks inarched under one branch, there were 390 cm. of new shoot growth (1935) concentrated on the two branches (" treated ") above the inarched rootstocks, while the growth of the remaining seven branches amounted only to 98 cm. The other tree in which the effect of the inarching was unmistakable was one that had a single rootstock inarched directly into a branch (see p. 382). It made no growth in 1934, but in 1935 the branch with the inarched rootstock made 55 cm. of new shoot growth, while the rest of the tree produced two shoots the combined length of which amounted to 10 cm. only. Thus, when one and two rootstocks, respectively, were inarched directly into a branch or into the trunk beneath a branch, a measurable effect was obtained, and this showed itself within two years.

SUBSEQUENT OBSERVATIONS.

It was intended in 1936 to continue only the gross measurements of girth and new growth at the end of the summer, but when the plot was inspected during the latter part of September the majority of the inarched trees were seen to be in a striking condition. Whilst certain branches had become almost defoliated, retaining only a few scorched leaves, others had fully retained their leaves which were healthy and normally green in colour (Figs. 3 and 4). Hence further records were taken under the direction of Beakbane.

In order that the effect of the inarched rootstocks could be studied in detail the main branches arising from the crutch of every tree were numbered and recorded separately. On October 6th, 1936, the total length of new wood formed during the previous summer was measured. In view of the variation in size from branch to branch the old wood was also measured, and the amount of new growth per unit length of old wood was calculated. The number of leaves on the current season's shoots was counted. The lengths of new and of old wood on each branch were added together to give a measure of the total size of the branch, and the number of leaves was expressed as number per metre of total branch length. (See Tables I to VII.)

Position of the Rootstocks.

As already stated, the exact positions in which the rootstocks were planted and inarched had been decided upon not only in relation to the "treated" branch which it was sought to influence but also in such a way as to cause least damage to the existing root framework of the tree. As a consequence, some of the rootstocks were inarched in a direct line exactly below single branches, whilst others were not. As will be seen later, this variation in position of insertion led to very interesting differences in the final results.

Roach had already found, in his work on tree injection, that if any control of the final distribution of the injected liquid is to be obtained, the point of injection must be determined by a careful consideration of the internal woody anatomy of the tree (6). Hence, without a knowledge of the actual quantitative results obtained, he was able to predict, solely from a study of the positions of the inarched rootstocks, what the relative distribution of the effect of the inarching among the different branches of the tree would be. In the following descriptions of the seven individual trees it will be seen that the predictions were in substantial agreement with the results actually obtained ; consequently the same principles may be applied to produce at will an effect either on a single branch, for experimental purposes, or on a tree as a whole when the inarching method is employed commercially in the orchard.

DETAILED RESULTS.

In the descriptions that follow, the seven trees are taken in the order of relative lopsidedness of heads that they showed, the most lopsided being taken first. In the Tables, the branches are arranged in order of decreasing wood growth, but it will be seen that the order would be nearly the same if the arrangement depended on decreasing numbers of leaves.

TABLE I.

Tree 3 (*on Crab H*):

1 *rootstock inarched by method B directly into a branch.*

Order of Branches.		New wood, cm. / Old ,, , m.	No. of leaves/total branch length, m.
Predicted.	Actual.		
4	4	19·0	8·86
1, 2, 3	1	1·0	0·17
	2	0·0	0·00
	3	0·0	0·00

As will be seen (Fig. 4), the inarched branch No. 4 alone was affected. All the other branches together produced only one shoot, 6 cm. long, of new wood, and at the time the record was taken (October 6th), only one leaf remained on it, whilst the branch with the inarched rootstock made 117 cm. of new wood which still retained sixty-five large, green and healthy leaves. It is quite evident, therefore, that one branch may be affected quite independently of the rest of the tree when the rootstock is inarched directly into it. In all the remaining experiments the rootstocks were inarched into the main trunk of the tree.

TABLE II.

Tree 7 (*on Crab H*): 3 *rootstocks inarched by method B.*

Order of Branches.		New wood, cm. / Old ,, , m.	No. of leaves/total branch length, m.
Predicted.	Actual.		
4	4	20·7	12·78
1	1	6·1	3·32
2, 3	3	4·6	1·89
	2	0·0	0·00

From each inarched rootstock a slightly projecting ridge about 1 cm. wide ran up the trunk. These ridges evidently resulted from increased local growth due to the inarched rootstocks ; consequently by tracing them it was easy to predict which branches would in all probability be affected by the operation. In Figs. 5 and 6 the outer margins of the two outside ridges are marked by the white lines, *a* and *b*, painted on the trunk. In Fig. 5 the ridge, bounded on its right-hand side by the white line *a*, could be traced up the trunk to a point a few inches below the fork made by branches 4 and 1, and it was predicted that its continuation led into branch 4, as indicated by the white line. As could be deduced from a close examination of the bark and from the relative sizes and spacing of the branches, there must have been strands of involved woody conducting tissue running between branches 4 and 2 and connected with branch 1, which therefore separated branch 2 from the strands coming from the rootstocks, so that branch 2 would receive nothing from the rootstocks ; and there were strands from the inarched rootstocks between branches 4 and 2 (Fig. 6) which reached branch 1. It was clear, therefore, that nearly the whole effect of the inarched rootstocks would be shown by branch 4, but that branch 1 would also be affected to a slight extent. The result of this experiment therefore is nearly as clear cut as that of the last one, in which a single rootstock was inarched directly into the branch.

The ridges of increased growth above each rootstock passed vertically up the main stem ; there appeared, therefore, to be no spiral twist in the trunk of this tree. The importance of a twist will be referred to in a later paragraph.

TABLE III.

Tree 5 (*on Crab H*):

2 *rootstocks inarched by method C on opposite sides of the main stem.*

Order of Branches.		New wood, cm. Old ,, , m.	No. of leaves/total branch length, m.
Predicted.	Actual.		
4	4	14·9	13·32
1	1	7·5	4·91
2, 3, 5	2	4·2	1·53
	3	0·0	0·00
	5	0·0	0·00

The inarched rootstock below branch 4 (Fig. 7) was stronger than the other one and had made a good union with the tree. There was a slight ridge (between the two white lines, also vertical) from the top of this rootstock to branch 4. The woody strands involved seemed unlikely to have reached branch 5 and certainly not branch 3. The weaker rootstock had made a good union on one side and a poor one on the other and there was no perceptible ridge running from it. The woody strands running from the good union clearly must have passed up into branch 1 and reached branch 2, but they probably did not travel up into this branch (see Fig. 8). A smaller proportion of branch 1 was affected than of branch 4.

TABLE IV.

Tree 2 (on Northern Spy): 3 rootstocks inarched by method A.

Order of Branches.		$\frac{\text{New wood, cm.}}{\text{Old ,, , m.}}$	No. of leaves/total branch length, m.
Predicted.	Actual.		
1	1	15·2	7·18
2	2	13·9	5·81
3, 4, 5, 6	3	9·4	4·78
	6	8·8	4·80
	5	5·0	3·27
	4	4·6	2·23

Assuming, as has already been seen in two instances of Grenadier on Crab, and as will be made clear later in describing Tree No. 1 (Grenadier on Spy), that the woody strands involved travel, like ridges, vertically up the trunk, it will be evident that the white line dividing the involved strands from the others on one side of the trunk (Fig. 9) corresponded with that dividing the woody strands of branch 1 from those of branch 4, and that on the other side the involved strands overlapped branch 2 (Fig. 10). There was therefore a band of involved strands travelling up on the inside of branch 2 and passing into its first crutch (x). It was evident that the main effect would be shown by branch 1, that branch 2 would be definitely affected and branch 4 might possibly be affected by a few strands but not enough for the effect to be detectable quantitatively. The remaining branches in all probability would not be affected at all. Table IV bears this out to a considerable extent.

TABLE V.

Tree 6 (on Crab H): 2 rootstocks inarched by method B.

Order of Branches.		$\frac{\text{New wood, cm.}}{\text{Old ,, , m.}}$	No. of leaves/total branch length, m.
Predicted.	Actual.		
1	1	20·7	12·78
2	2	21·0	8·03
3	3	18·9	4·88

The margin of the involved strands on the side nearer to branch 2, i.e. on the right of the white line in Fig. 11, seemed to travel up branch 1, leaving a band of uninvolved strands on its left, between the two branches. The other marginal strands travelled along the longest white line in Fig. 12, up between branches 1 and 3, in all probability touching, but not travelling up, branch 3; this branch was not likely to be appreciably affected. There was a band of involved strands travelling up between these two branches into branch 2, between the central white line and the longer one on the right. Nearly all the strands supplying branch 1, about one tenth of those belonging to branch 2, and possibly a negligible quantity of those supplying branch 3 were involved. From the Table it will be seen that whilst the proportion of new leaves seems to bear out the prediction absolutely, the percentage of new wood was practically the same for all three branches.

TABLE VI.

Tree 4 (on Northern Spy): 3 rootstocks inarched by method A.

Order of Branches.		New wood, cm. / Old ,, , m.	No. of leaves/total branch length, m.
Predicted.	Actual.		
4	4	22·9	15·10
2	2	19·5	13·10
1, 3	1	19·4	14·59
	3	7·0	5·07

The main mass of strands involved belonged to branch 4 (Fig. 13). Marginal strands passed up between branches 4 and 2, as indicated by the white line, in all probability on the branch 4 side of the junction; the other margin was almost certainly on the branch 2 side of the dividing line (Fig. 14), between it and branch 4, and there was a band of involved strands travelling up into the crutch between branches 4 and 2, and thence up into branch 2 and into its first crutch. The main effect of the inarched rootstocks was therefore to be expected in branch 4, a small effect in branch 2 and none elsewhere. This prediction agrees with the actual results given in the Table, except for the unexpected vigour of branch 1.

TABLE VII.

Tree 1 (on Northern Spy): 3 rootstocks inarched by method A.

Order of Branches.		New wood, cm. / Old ,, , m.	No. of leaves/total branch length, m.
Predicted.	Actual.		
1	3	12·1	13·54
3, 4	4	12·4	7·95
2	2	7·3	7·66
	1	4·6	2·95

In the autumn of 1935, one season after the inarching, Hearman examined this tree by an injection method. Two small holes, diameter 2 mm., were punched into the wood in the trunk, one on each side of the group of inarched stocks. A tapered glass tube, open at both ends, was fitted into each hole, filled with dye and left for about two hours. The path followed by the dye thus marked the strands in direct communication with the inarched rootstocks. Small " windows " (*y*) were cut through the bark to expose the wood across the path which the dye might be expected to take, and by this means its path was located and traced out. Some of the strands from the inarched rootstocks were in direct connection with branch 1 (Fig. 15) ; others, on the left of these, passed up into branch 4. On the other side of branch 1 (Fig. 16) the dyed strands passed up into branch 3 and some into branch 2. As this dye examination suggested, all the branches were likely to be influenced, but it does not explain why the effect on branch 1 was so comparatively small.

EXPERIMENTS WITH
A HALF-STANDARD GRENADIER ON SPY TREE.

In addition to the above seven bush trees, a fifteen-year-old half-standard tree (Grenadier on Northern Spy) growing on another plot, was inarched at the same time (February 1934) with three rootstocks. In October, when the leaves were still on the tree, the trunk and the rootstocks were cut through about three inches above the ground ; the end of the trunk was placed in a dish of patent blue dye, the cut ends of the two outside inarched rootstocks (Nos. 1 and 3) were placed in yellow dye (tartrazine) and that of the middle one (No. 2) in acid fuchsin (red).

The absorption of dye solutions was allowed to continue for twenty-four hours, the bark was then stripped from the trunk and the rootstocks to expose the dyed wood to view. The result is represented diagrammatically in Fig. 17. This treatment revealed the existence of a twist in the trunk, and thus the central inarched rootstock was directly connected with woody strands that passed into all three main branches of the tree. The greater proportion of them, however, were connected with the branch that had been selected as the " control ", and not with the " treated " branch vertically above the middle one of the three inarched rootstocks. Dye from the other two inarched rootstocks travelled up the tree in similar fashion, as can be seen from the diagram. Hence, in this case, when the inarched rootstocks united with strands that went into the crutch of the tree, the materials were distributed to all the branches, and they were influenced in varying degrees. To use one branch of a tree of this kind as a standard by which to compare the growth of another part of the same tree would give a misleading idea of the result of inarching. Evidently a considerable length (4 ft. 6in.) of trunk between the inarched rootstocks and the branches would necessitate very careful placing of the rootstocks if it was desired to influence one individual branch ; and the possibility of the existence of twist would have to be taken into account. This experiment, however, suggests very clearly where inarching should be effected in order to influence the whole tree uniformly, as would be the aim in a commercial plantation. As a result of the twist in the 4 ft. 6 in. " leg " of the tree, the inarched rootstocks, instead of

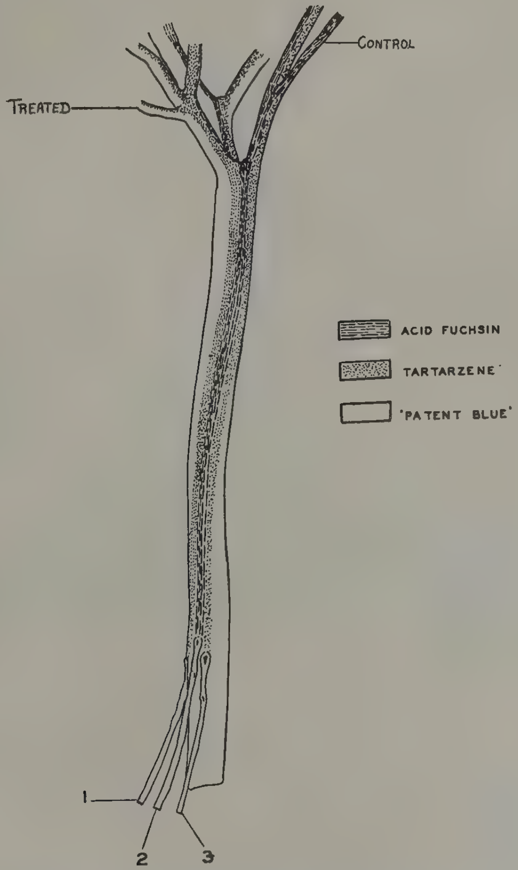


FIG. 17. Diagram illustrating the paths which the dyes from the three inarched rootstocks followed up the trunk and into the branches of the fifteen-year-old Grenadier tree on Northern Spy stock.

being brought into connection with woody strands passing into the branch vertically above them, as was intended, actually became connected with strands that passed into the main crutch, and thus were they placed in an ideal position for affecting the whole head of branches.

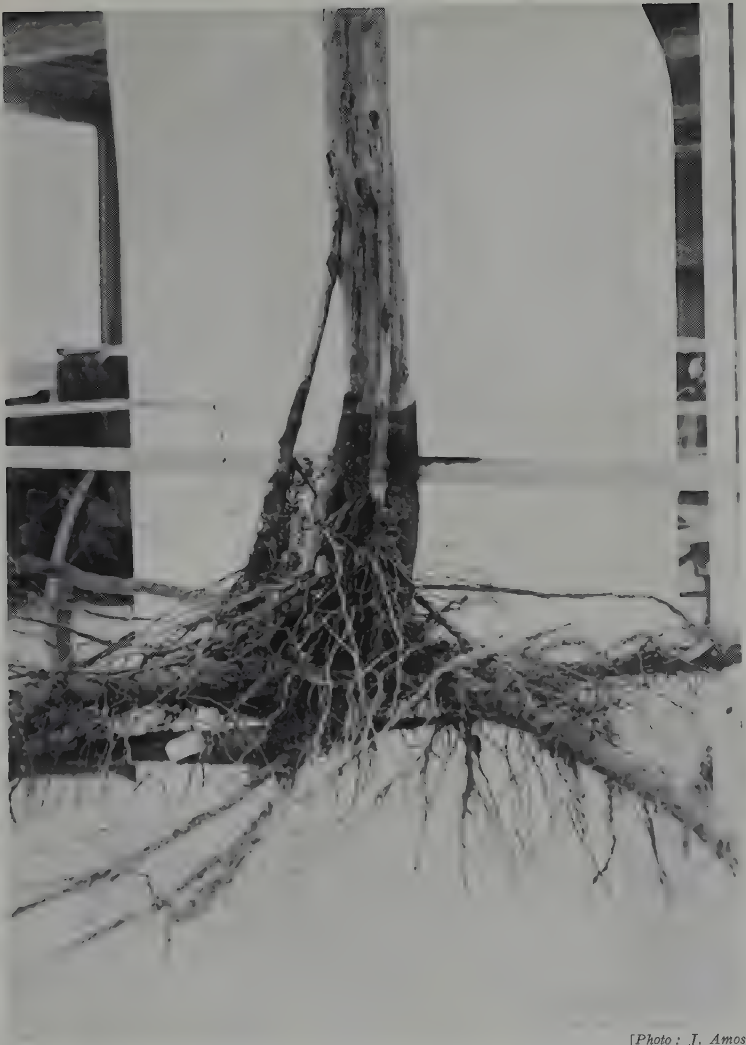
BEHAVIOUR OF THE ROOTS OF THE INARCHED ROOTSTOCKS.

The complete root systems of the experimental tree just described, and of the rootstocks inarched into it, were excavated and re-erected (Figs. 18 and 19). In spite of being rather close together and having been planted amongst the well established roots of the experimental tree, the inarched rootstocks had developed quite vigorous root systems, the most striking point being the unexpected depth to which their roots had descended. Comparatively few of these roots were found spreading above the large scaffold roots of the original Northern Spy stock. Most of them had found their way between the scaffold roots, and many had, in two seasons, penetrated to a depth of 50, 60 and even 80 cm. from the surface, and were located directly below the trunk of the experimental tree, the Northern Spy roots of which had not occupied this region. By comparing Figs. 18 and 19 it can be seen that the roots from the inarched rootstocks formed a dense mat almost immediately below the trunk of the tree, a position which it has been shown (4) the roots of Northern Spy seldom occupy to any considerable extent.

It is interesting to note that Thomas (8) has also observed that when vigorous apple seedlings have been inarched into trees propagated on stocks having a surface rooting tendency, the roots of the inarched seedlings penetrate to considerable depths.

GENERAL CONSIDERATIONS.

The seven inarched apple trees, dealt with in detail in the previous paragraphs form a series in which the earlier ones show that when vigorous clonal rootstocks are inarched either directly into a single substantial branch or into the trunk some distance below individual branches, these branches show increased growth independently of the other branches. The later ones demonstrate that the whole head of branches may be beneficially affected more or less uniformly when the rootstocks are inarched, not below individual branches, but between them. This method of inarching, therefore, can be adopted for the reinvigoration of debilitated, established trees in commercial orchards. The first method is evidently one that may be of considerable value in research work, in which, for example, it may be desired to compare the behaviour of one or more particular



[*Photo: J. Amos*

FIG. 1. Base of lifted fifteen-year-old tree of Grenadier on Northern Spy, into the trunk of which three Malling No. XVI rootstocks were inarched by method A (see text p. 386). The rootstocks were planted, as shown, between the main framework roots of the established tree. The bark of the tree and of the overground parts of the rootstocks has been removed almost down to ground level.

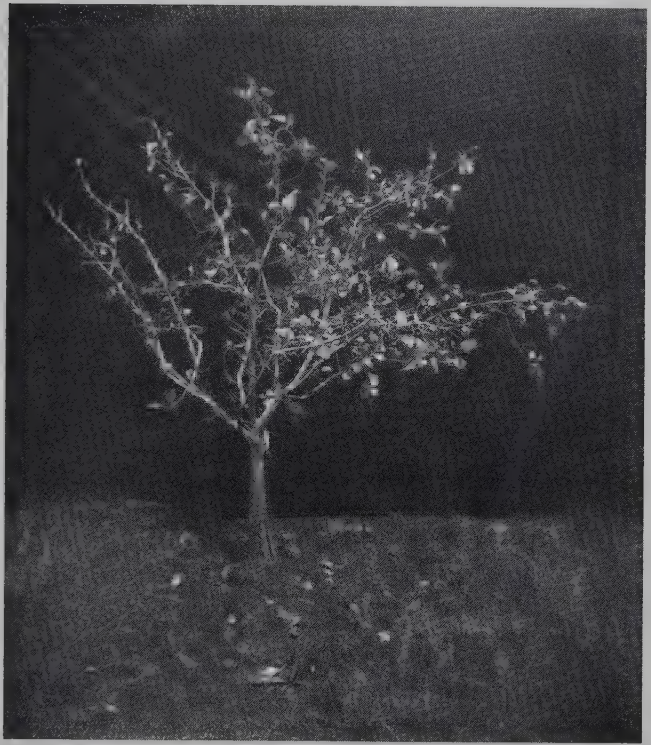
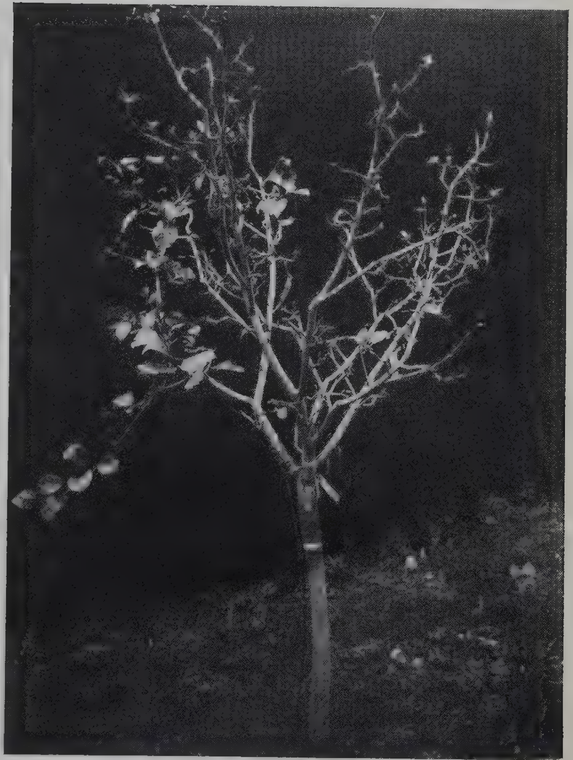


FIG. 3. Grenadier tree on Crab H stock showing effect of inarching three No. XVI rootstocks, two of which are visible. Note greater number of leaves remaining on branches on the same side of the tree as the inarched rootstocks. (See p. 381.)



[*Photos: J. Amos*

FIG. 4. Showing effect of inarching one No. XVI rootstock (on left) into a single branch of a debilitated tree.

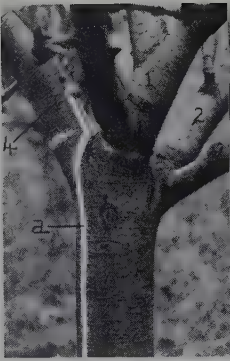


FIG. 5.

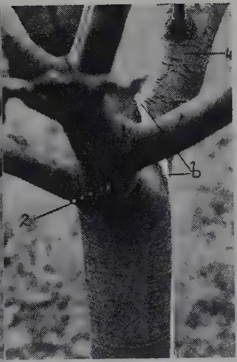


FIG. 6

(See p. 383.)

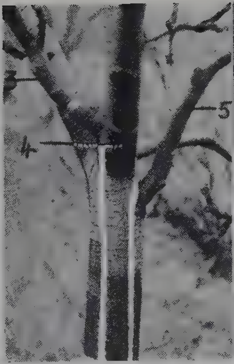


FIG. 7.

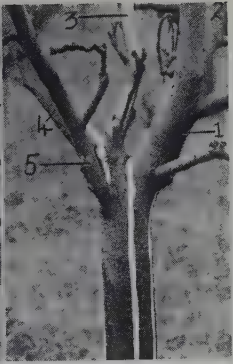


FIG. 8.

(See p. 383.)

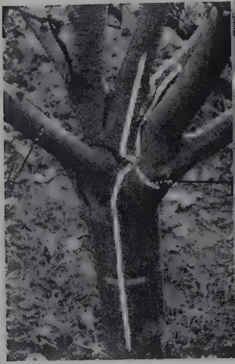


FIG. 9.

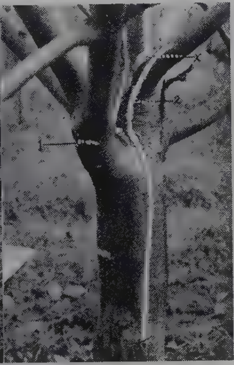


FIG. 10.

(See p. 384.)

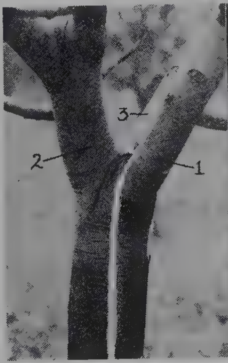


FIG. 11.

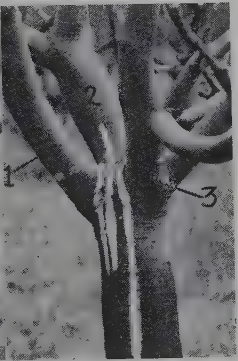


FIG. 12.

(See p. 384.)

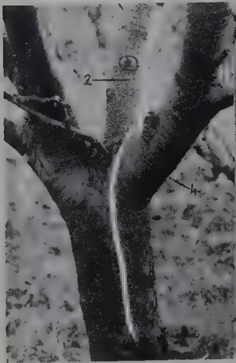


FIG. 13.

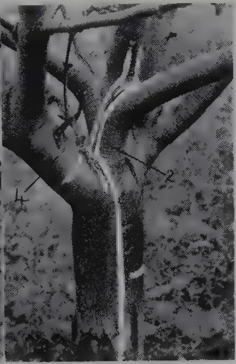


FIG. 14.

(See p. 385.)

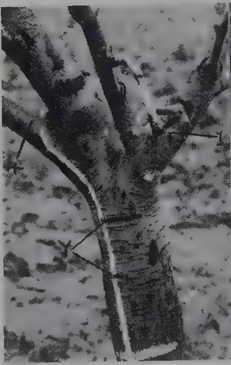
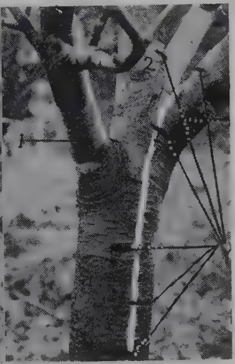


FIG. 15.



Photos: B. F. G. Levy

FIG. 16.

(See p. 386.)

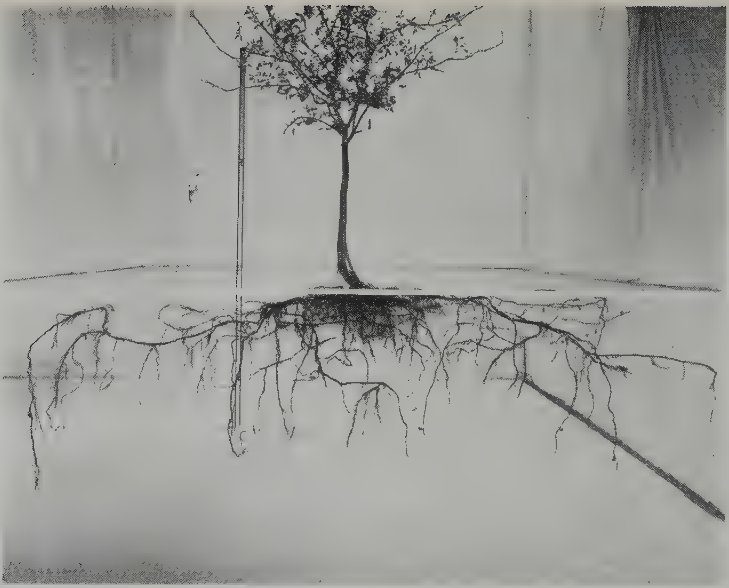
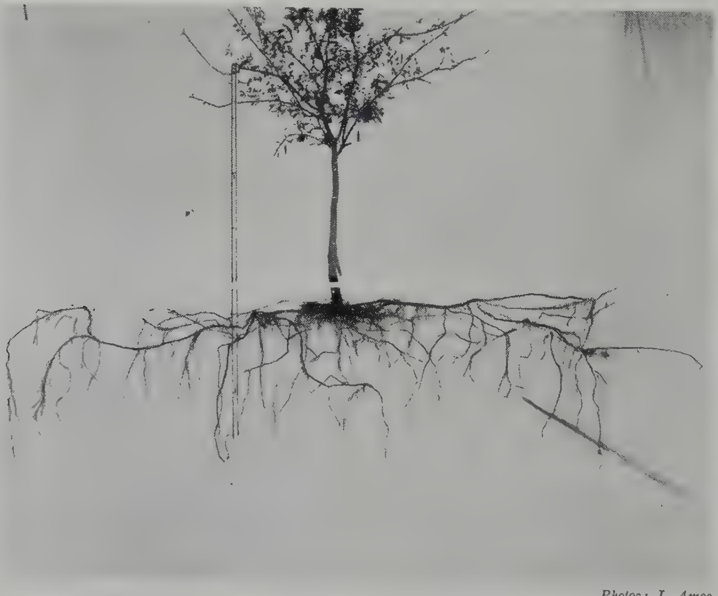


FIG. 18. A fifteen-year-old Grenadier tree on Northern Spy inarched with three No. XVI rootstocks. Root systems of inarched rootstocks present.



Photos: J. Amos

FIG. 19. The same tree as shown in Fig. 18. Root systems of inarched rootstocks removed.

branches under a given set of circumstances with other branches. The tree, in fact, can be used as a " plot ".

The experiments demonstrate clearly the importance to be attached to the point in the trunk at which the inarch should be made. As to height, in view of the difficulty of being sure whether a point low down on the trunk is or is not in direct vascular connection with a particular point in the crutch, it is advisable that the junction of rootstock and trunk should be made as high up and as near the crutch as the length of the rootstock will permit. This is particularly important in trees in the trunks of which a twist exists. As to circumferential position, this will be determined by whether the intention is to influence the whole head or only a certain branch or branches of it.

The experiments show, further, that by carefully studying the external features of the head and trunk of a tree a reasonable prediction can be made as to what parts of the head are likely to be affected when rootstocks are inarched in any given positions.

The experiments are also of particular interest in that they give what is perhaps the clearest indication so far obtained that the root systems of different varieties of rootstock, starting from the same point and ramifying through the same soil, distribute themselves differently and make very differing degrees of use of the nutrients stored therein.

The fact that this soil had already been occupied for a number of years by the older root system makes the greater efficiency of the inarched root systems all the more striking.

ACKNOWLEDGMENT.

The authors wish to thank Dr. G. H. Pethybridge for many valuable suggestions concerning the presentation of this paper.

SUMMARY.

1. The method of inarching apple seedlings has been used commercially overseas for improving the performance of unthrifty apple trees without other alteration in cultural treatment, and with a considerable amount of success.

2. The studies here described showed that inarching vigorous apple rootstocks into the trunk some distance below the branches of established but debilitated apple trees led to a marked increase in vigour by the end of three seasons.

3. The main effect of the inarching was shown by those particular branches of the trees which were in direct vascular connection with the rootstocks.

4. When the rootstock was inarched direct into a single branch, this branch has, up to the present, shown the main or entire effect, and other branches of the same tree have remained unaffected; they may therefore be used for comparison for estimating the effect of the inarching.

5. When the rootstocks were inarched into woody strands which divided at the main crutch and ran into two or more branches, the whole tree was affected.

6. When the trunk has a spiral twist, account of this must be taken when deciding on the point of insertion of the rootstock.

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A NOTE ON THE ABSORPTION OF SOLUTES BY LEAVES

Considerable interest has centred in recent years on the possibility of supplying nutrient materials to plants by direct absorption through the leaves, both in cases of positive deficiencies of certain ions and with the aim of increasing yields in normal practice. In view of the obvious commercial possibilties of this latter aspect especially, work was begun on the estimation of the amounts of solutes absorbed by the leaves of lettuce plants. Unfortunately the work had to be abandoned at an early stage, but as positive evidence was obtained of the absorption of an ion not previously recorded as being absorbed in this way, it is thought that the results of these experiments are worth putting on record.

Lettuce plants of the variety Loos Tennisball, grown in soil in pots, were sprayed by means of a large atomizer with a dilute nutrient solution containing potassium sulphate, potassium phosphate and sodium nitrate. Due precautions were taken to avoid spraying the soil with the solution in one of the treatments and adequate replication and control of positional effects was ensured.

The plants were sprayed daily for five weeks and were then cut off at the root, the tops being washed and chemically analysed. No significant differences were found in potassium or in protein nitrogen content between control and treated plants, but a marked and statistically significant increase in phosphorus content was noted in the sprayed plants. The figures obtained were:

Treatment.	P_2O_5 *as % of dry wt.*
Sprayed on leaves only	0·85
Sprayed on leaves and soil	0·79
Sprayed water only (control)	0·65

The significant difference for the 1 per cent. level of probability calculated from the "t" test is 0·062 and the observed differences greatly exceed this value.

The values for phosphate are all definitely sub-normal for lettuce, and this is correlated with the fact that the field from which the loam for the potting-compost was obtained was later found to be markedly deficient in phosphate.

It appears therefore that phosphorus may be absorbed by the leaves of lettuce plants, at least when the soil in which they are growing is deficient in this element.

From The Department of Horticulture, University of Reading, by

D. Lewis.

BOOK REVIEWS

STATISTICAL METHODS FOR RESEARCH WORKERS. By R. A. FISHER. (Sixth Edition. Oliver & Boyd. Edinburgh. 1936. 15s.)

That six editions of this book have been called for in the space of eleven years, is sufficient indication of its success, and of the need that is felt by workers in the biological field for an improvement, not only in the technique of statistical analysis but also for an increase in the efficiency of experimental design and in the certainty of inferences that can be drawn from experimental results.

The sixth edition follows its predecessors in including new sections on points on which progress has been made. No attempt, however, has been made to expand the chapters dealing with the design and analysis of replicated experiments. Instead, Professor Fisher has followed the wise course of publishing an entirely new book, *The Design of Experiments* (which has already reached its second edition). Research workers in the horticultural field who are interested in the latest developments in the design of field experiments should therefore refer to this latter work.

F.Y.

HARDY FRUIT GROWING. By Sir FREDERICK KEEBLE and A. N. RAWES. (334 pages. Macmillan & Co. Ltd. 1936. 16s.)

The wider knowledge and higher standard which horticulture now demands from its workers make it increasingly difficult for one person to cover the whole ground with authority.

The volume before us is probably only the first of many where the knowledge of chemistry and plant physiology will come from one author and the cultural experience from another. In the present case it would be hard to find two more suitable collaborators, Sir Frederick being a botanist who is also a gardener, and Mr. Rawes' long experience at Wisley having brought him into touch with both practice and science.

Interesting though it would be, we will not attempt to find the points where the voice of Jacob gives place to the hand of Esau, and indeed it would be difficult, so well are the seams concealed. Let us turn rather to the scope and object of the book by which alone can its merits be judged.

The authors have aimed, they tell us, at a presentation of the principles and practice of fruit culture for the use of the amateur and the commercial grower. Both a first and second glance show that the fruit grower has got the better of the deal; in fact it would seem that the book has been written mainly with his needs in the authors' minds. Amateurs, it is true, are of many kinds, from the beginner stumbling through his ABC to the old hand skilled in all the niceties of summer pruning and porcupine grafting.

It is obvious at once that this is no Primer for the beginner; no pictures comparing fruit- with wood-buds are given or other elementary information, such as the various forms of trees and shoots and their nomenclature. When we consider the needs of the advanced amateur we find that he, too, has not been very well catered for in certain details; for instance, the nice operations of peach pruning, training and laying in of wood are dismissed in less than one page, and the culture of apricots receives but little more space.

The main value of the book and its originality, therefore, lie rather in the very excellent chapters on soils, manures, insect pests and descriptions of the inner processes of plant life which are of the greatest value and interest to amateur and "grower" in their attempts to form a picture of the growing plant and its needs.

As the authors generously admit, commercial fruit growers must turn to Mr. Seabrook's indispensable volume for the purely commercial side, such things as marketing and profits or losses.

In the matter of selecting varieties, the authors show a wise conservatism and will gain the approval of most experienced fruit growers; discussion of opinions on this could obviously carry on at great length. Let us confine ourselves to facts and merely point out that no market grower now plants the Red and White Filbert, or the true Ohio Cherry, as recommended. Lord Derby apple is again very much out of favour with modern growers.

The information on various stocks is of great value and interest, but it is a little misleading to suggest that standardized stocks and the control of tree growth that they give is entirely a matter of recent knowledge; the pioneer work of Thomas Rivers at once shows that such knowledge in England goes back some fifty years. That practice since then did not always equal precept does not justify the conclusion that ignorance had previously prevailed.

One other point of disagreement must be mentioned before we pass to the more pleasant task of noting our agreements. It is recommended the early pears "should be picked daily as they ripen" (page 141) and on the following page a fruit is declared to be ripe when it "almost drops off into the open hand gently placed beneath it". Anyone who allows his William's or Colmar d'Été pears to reach this stage will suffer a grievous disappointment; they must be gathered, even in the private garden, when still green, and forcibly gathered, if they are to be anything but bags of mealy starch. Thinking perhaps that pears had by a slip been bracketed with apples in this matter, we turned to page 144, but we find there the advice repeated. The advice to eat early apples from the tree we cordially endorse, even a few days in the fruit room robs an Irish Peach of all its quality.

One of the most valuable features of this work is the excellent account of pests and their remedies which will make it a work of constant reference. It is also convenient to find the recent work on sterility and incompatibility and times of flowering gathered in the covers of one volume.

As above-mentioned, the chapters on soil preparation, treatment and manuring are admirably set forth; and, beyond the question of pruning, which for some reason always arouses fierce passions and so will not be discussed here, they will serve for many years as masterly expositions.

The twenty illustrations are from excellent photographs and are well reproduced, but they have a suggestion that they did not grow with the book but happened to be handy when it was completed. Two very similar photographs of grease banding and two general views of a plantation could have been reduced in favour of some more figures of plant pests and the indications which the tree shows of their presence.

Apart from the exceptions quoted above, we can cordially recommend this work to the advanced amateur, and the commercial grower will find it a valuable supplement to Mr. Seabrook's well-known work, strengthening it on the so-called "scientific" side, as his book usefully supplements our authors' on the commercial.

The main criticism which will be brought, we imagine, is a certain lack of balance between the amateur's needs and those of the professional. The reviewer feels, too, a danger of this charge being brought against this present attempt at evaluation.

It is the misfortune of the tribe of critics that praise can be given without illustration, whereas differences of opinion or challenging of facts require some evidence and quotation and thus take up a disproportionate space.

The authors, we feel sure, will appreciate a candid expression of opinion in view of future editions, and our readers will see that, on balance, here is a useful piece of work well done which no grower of fruits, large or small, will read without profit and enlightenment.

EDITORIAL NOTE

We are pleased to welcome Dr. G. H. Pethybridge on the Publication Committee, and glad to acknowledge his very considerable help to the Joint Acting Editors in preparing the present number of this Journal for press.